THE

EARTH AND ITS STORY

A FIRST BOOK OF GEOLOGY

BY

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SILVER, BURDETT AND COMPANY

NEW YORK . . BOSTON . . . . CHICAGO

1897

Typography by C. J. Peters & Son, Boston.

Presswork by Berwick & Smith.

PREFACE.

In the preparation of this volume it has been the aim of the author to present briefly, forcibly, and possibly in a more popular form than in most books of a similar nature, the general facts of geology. In its relation to the more advanced and technical treatises on the subject this work may stand as introductory, and yet independent by itself. While its treatment of the science of geology is not burdened with numberless details, nor made too analytical in method, it is believed to be sufficiently comprehensive to meet the needs of the average student, and to appeal to the large class of readers who would pass by a difficult technical work, and at the same time would not be satisfied with a mere elementary text-book.

The author is conscious of the difficulty of compressing into a limited space the mass of material that bears upon the subject, and has found it necessary to leave untouched many points which might otherwise have been exhibited. It is thought, however, that nothing has been omitted which is vitally essential to a complete, popular treatise; and perhaps the combination of brevity, compactness, and fulness in the work, while not over-taxing the patience of the reader, will secure from him a larger amount of attentive study than if the volume were more extended and technical in its character.

The illustrations are, in the main, reproductions from photographs taken in the field, and are, therefore, trustworthy in their representations. A mere sketch or diagram, which has hitherto been the principal resource of geological text-books, has none of the advantages of a perfect photographic picture of Nature, and while certainly useful in its place, fails, as most teachers well know, to harmonize the facts of the classroom with those of the field.

The work is commended to classes in high schools and colleges, and also to the large and increasing number of lay readers who are desirous of knowing more about the formation, structure, and development of the earth on which they live. As students they will find new wonders in the structural history and the rare phenomena which science is continually unfolding from earth and sea.

It is but proper to add acknowledgment to the many friends who have so kindly assisted the author, especially in the securing and preparation of photographic material.

A. H.

ACADEMY OF NATURAL SCIENCES,
PHILADELPHIA, *June*, 1896.

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THE EARTH AND ITS STORY.

PART I.

CHAPTER I.

WHAT THE ROCKS TEACH.

MOST persons have rather vague notions regarding rocks. In my daily walks through a neighbor's field I pass a great rock, which has stood there for hundreds of years before I was born, and my farmer friend tells me that it grew there, and that it still grows. As with many other things that take place on the earth, and of which we know little, we believe what we are told, and ask few questions. Our worthy farmer had not seen this one rock actually growing; but he had observed that other rocks or stones which were new to him appeared upon his field, and he concluded that they came there by growing. He did not ask himself how they grew, or how anything could grow without having real life in it; but he was satisfied, just as hundreds of thousands of other people are, with the simple fact as it appeared to him.

The Decay of Rocks. — In truth, however, that rock, like almost every other rock, grows only in one way —

smaller and smaller every year, every month of that year, and every day of the month. We all know how readily rock crumbles. We can hardly go anywhere in the country without meeting with some proof of it. The very dust that lies in the roadway is a part of the underlying rock or stone, powdered in one way or another; the mud through which you have struggled so hard to make your way is the same material mixed with water; and the bowlders that lie at the foot of the mountain side are merely parts of the mountain that have broken away and fallen to the bottom. Even about the big rock which has so long troubled farmer Smithers, I to-day found bits and fragments of its own material scattered, so that here, as elsewhere, the evidence of destruction is plainly visible. We have learned our first lesson in geology: *All rocks undergo destruction or decay, and sooner or later disappear.*

The Causes of Decay in Rocks. — When we ask ourselves the question why it is and how it is that rocks crumble or decay, it is not easy to give the same answer for all cases. Some rocks crumble in one way, and some in another; some rocks are much tougher than others, and stand apparently unchanged for perhaps a century, while others decay so rapidly that they are changing with almost every day. One of the surest ways to destroy a rock is to allow water to soak into its joints or pores, and there do just what it often does in winter in the water-pipes of your own house: it freezes, and, by expanding, forces the mass apart. Tons of rock are in this way split off from the mountain side every winter; but although the force is great, that does not prevent it from splitting off small fragments. Large

Plate 1.

1.

2.

ROCK DISINTEGRATION.

1. Granite breaking into bowlders, Rocky Mountains.
2. Disintegrated trap-rock of Pottstown, Pa., — a "Felsenmeer."

Plate 2.

1.

2.

ROCK DISINTEGRATION.

1. Mountain disintegration in the Alps; the accumulated débris on the right constitutes a "Talus."
2. Weathered æolian rock of the Bermudas.

and small, they all go to the destruction of the rock. So well does the stone-cutter know this method of breaking rock, that oftentimes, in quarrying for his blocks, he simply inserts a number of wooden stakes in drill-holes, allows these to expand by water, and then waits for the inevitable result.

Another way in which rock crumbles is through the alternate swelling and contraction which it undergoes in passing through extremes of temperature. We well know that nearly all bodies expand or swell when they are heated; and we know equally well that they shrivel or contract in the process of cooling. Now, where the extremes of heat and cold in the atmosphere are specially great, or follow one another in quick succession, the rock, in adapting itself to such changes, is liable to respond with insufficient rapidity, and the result is that it splits to pieces. Especially is this the case in desert regions, where the heat of day is almost intolerable, and where at night ice often forms. Travellers in such regions have actually seen the chips fly, and more often have heard them crack.

A third method which produces decay in rocks is one that cannot be watched so easily. It is something that goes on inside, and does not permit its doings to be followed by the eye. When you leave a knife or shovel out of doors in a damp night, you are not surprised in the morning to find it more or less rusty. Iron-rust is merely a combination of the metal and some of the gas substance of the atmosphere known as oxygen; the two have united, and they now form the new combination. How often in your wanderings through a city have you noticed ugly yellow or reddish stains on the surfaces of stately marble or granite buildings; white marble doorsteps and window-sills are much in the same way. When this is the case, the fact tells us that iron has rusted within the rock, and perhaps this is the first suspicion that we have that the rock contains iron. There are within the rock other substances besides iron which tend to take in the oxygen from the atmosphere; they also "oxygenate," or burn, or rust, but when they do this they produce changes in the rock, and these changes are generally in the direction of decay. New combinations are formed, and old ones are destroyed. Hence, geologists say that one of the prime agents in producing decay is the taking in, by the rock, of oxygen from the outside, and the making of new chemical combinations within. Our second lesson in geology teaches us that rocks crumble or decay in two ways of their own, mechanically and chemically. Hence we say: *Rocks undergo mechanical and chemical destruction or disintegration.*

The Weathering of Rocks. — I often sit in the lonely little graveyard that adjoins the country parish church, and muse over those quaint inscriptions on the tombstones which tell of peaceful deaths in years gone by. Some record the years 1720 and 1725, others go back a half-century or more, while still others remind us that life has only recently departed. I notice, too, that some of the oldest inscriptions are seemingly as fresh as though they had been cut yesterday; many of the newer ones, on the other hand, are nearly wiped out, and bear the rude traces that weather and time have worn upon them. When I still believed, with my good farmer, that rocks grew, this difference in the inscriptions puzzled me; but knowing now, that, instead of growing, all rocks break away, it is not difficult to account for the difference. Some have stood the influences of the atmosphere better than others — they have *weathered* more lightly. The marks may be older, but they have stood the tests of time more firmly than their neighbors. Who has not at one place or another observed how differently some rocks behave before the atmosphere than others; how some break before the pounding surf of the ocean in one way, and some in another? These peculiarities are a part of the structure of the rock; they are born with it, and in a measure shape its future course. Who does not know that some rocks when they break, break in rounded masses, that others break in sharp and angular blocks, and that others wear away with smooth and flowing lines? Whether destroyed in one way or another, they, to use a geological expression, "weather differently." The finer elements of scenery — the rugged cliffs and needles, the domes, the undulating knolls and meadows — are largely the result of this irregular weathering; that is, of the way in which different kinds of rock stand exposure to the assaults of decay and destruction. Just what it is that gives to different rocks their distinctive methods of wearing or weathering is not always clear; but so persistent is the form of decay for certain classes of rock, that an experienced eye can frequently detect the rock that lies ahead of him, without having first seen it, from the contour of the landscape alone. (Plates 1, 2, 13, 48, and 49.)

Desert Sands and Deserts. — Only a few years ago it was a common belief that the sands of the desert represented an old ocean bottom which, in one way or another, had been lifted out of the sea and made dry — or, at any rate, the water that had covered it had been removed. To-day we know that this is not strictly the case; for whether the region had ever been beneath the sea or not, the sands are merely the decomposed parts of the solid rock that underlies them. The desert, indeed, is not that uniform expanse of sand which perhaps most persons still believe it to be; but it shows ranges of rocky hills and mountains passing through it in various directions, and it is from the destruction of these that the sands have come about. They are just the counterpart of the dust and mud on the highway. The reason that we have so much sand accumulated in desert regions is because in such regions there is little rain-fall and consequently but few streams; necessarily, therefore, the sand remains where it was formed, and only adds itself year by year to a steadily increasing quantity. Were there a sufficient number of streams to carry it away, as we find in more favored countries, there never would be any great thickness of it, except possibly in the line of some wind-drifts. We never have very much dust on our roadways, because the rains and streams every little while carry away what has been formed; but we do find that, when rain has ceased for a long time, the quantity of dust very materially increases during the period of drought. We are here brought face to face with an important lesson: *The materials of destruction of the earth's surface are distributed by the rain-waters and the streams resulting from them.*

The Course of Mud and Sand. — We now ask, where do these materials go? They can only go where the streams take them, and by far the greater number leisurely travel to the sea. A few there are which dry out or lose themselves before they reach the sea; and a few discharge into lakes or interior seas which possibly have no outlet. In such cases the materials which they carry are dropped along the route of their journey, some of it distributed here, some of it elsewhere. In lakes they help to build up the bottom; on plains and meadows they help to raise the surface. But by far the greatest quantity of the material follows the large rivers to the ocean, and there it is dropped; what becomes of it after that we shall find out later on. Thus it is that, seeing all parts of the earth's surface undergoing destruction and being carried oceanward by the numerous rivers, we frequently say, "the earth is on one grand march to the sea."

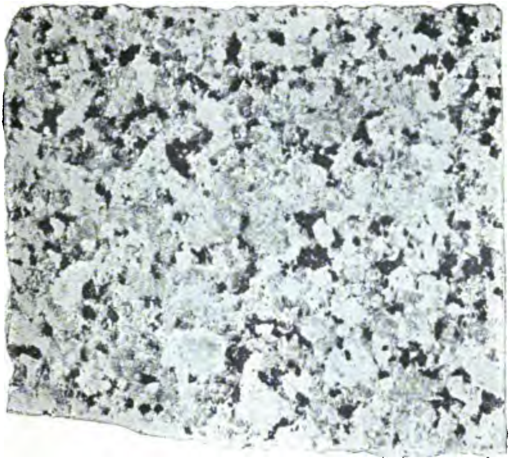
CHAPTER II.

SOME OF OUR COMMONER ROCKS, AND HOW THEY ARE MADE.

Sandstone is one of the commonest of rocks, and it is to be found almost everywhere. In our large cities, like New York, Chicago, Philadelphia, and Boston, it is much used as building-stone, and makes up what is familiar to us as "brownstone" and "graystone fronts." It may be brown, red, yellow, white, or, in fact, almost any color; and of whatever color, it hardly differs in structure. If you run your eye closely over the specimen that has just been obtained at the stone-yard, you will note that where freshly broken, it is a rough rock, and that this roughness is in the main due to innumerable glassy particles which come to the surface. You will immediately recognize these particles to be the same as the sands of the sea-shore. Scratched with a knife, the rock gives out a hard grating sound, which shows its toughness; a tiny piece put between the teeth makes them grit in the same way that sea-sand would were it put in the same position.

However plainly sandstone shows itself to be built up of innumerable sand particles or grains, it does not so clearly teach us how these grains are united together to form a compact rock. Sometimes, through hard pressure, especially where we are assisted by moisture

Plate 3.



1.

2.

1. A piece of granite: the dark spots are black mica; the gray areas are quartz, and the white, feldspar.

2. A piece of gneiss, showing a V-shaped fold, and the foliated structure of the rock.

Plate 4.

1.

2.

3.

1. A piece of pudding-stone, or conglomerate. 2. A piece of shell-rock, coquina. 3. A fragment of crinoidal limestone, showing fragments of crinoid stems.

of some kind, we can make loose particles not only stick together, but hold together for an almost indefinite time. We have all observed how the salt on our tables is "lumped" by the spoon being put into it too frequently, or how the loose earth of our back yards, with the addition of a little water, can be "patted" out into movable bricks. Nature does an enormous amount of patting and pressing, as we shall learn further on; and, doubtless, many of the solid rocks of the earth have been built up firm from loose particles through long-continued compression alone. The recognition of this fact is an important step towards understanding what a rock really is, and how it does not materially differ from the loose materials that everywhere surround us. Indeed, geologists frequently speak of loose sands, of clays, and even of water, as rocks.

Pebble-Rocks or Conglomerates ("Pudding-Stones"). The other day I received from a genial sea-captain of our coast a ship's bolt which had been buried in the sea for about twelve years; the good ship to which it belonged had gone to the bottom by striking a pebbly shoal, and its materials were lying scattered about beneath the angry waters. There was little strange about the bolt itself, which was badly rusted, but completely sheathing it for a length of some twenty inches or more was a case of small yellow and red stained pebbles. I could draw the bolt in and out of its case, just as you can draw a sabre from its sheath. It was plain that the pebbles had been united to one another through iron-rust, which acted first as a soft cement and then hardened; and this work of building up a solid rock of loose pebbles was accomplished in a period of twelve years.

Country folks frequently speak of a rock common in their region as "pudding-stone," so called from a fancied resemblance of the rock to plum-pudding; it is made up of innumerable pebbles, the "plums," which are held together much in the way of the pebbles of my bolt-sheath. To the geologist such a pudding-stone is known as *conglomerate*, and he recognizes in it a vast association, or conglomeration, of rolled rock-fragments, the pebbles, which have united to form a compact rock. And oftentimes this rock extends for miles across the country, and measures hundreds of feet in thickness. It is not iron-rust alone that acts as a cement; more often, perhaps, it is a lime-paste, or the substance of limestone and marble dissolved in water. Many waters hold this substance in solution, and invisibly, until for some reason or another it is dropped out, or "precipitated" as geologists say. (Plate 4, Fig. 1.)

Where the Materials of Sandstone come from. — The study of a piece of sandstone teaches us, apart from what the rock itself is, how loose materials may be and are compacted into a hard rock: by compression, by chemical union (as in the case of iron-rust and lime bindings), and by the combination of the two. The sandstone itself is a union of particles or grains of (quartz) sand, generally held together in one of the methods here indicated. It may be fine grained or coarser grained, as are many of the millstones (the so-called "grits"), and from the latter we easily pass to the pebbly conglomerates or pudding-stones. We have not yet asked ourselves the question: Whence come the sands which make up sandstones, whence come the pebbles that make up pudding-stones? You have frequently walked over them in your quiet rambles on the sea-shore; but perhaps the thought never entered your mind that the beautiful strand which catches the falling waters, whether of sand or of shingle (pebble), is the substance of possible future rocks. It has been brought where it is from the breaking up of other rocks, the same that my farmer friend assured me grew on his meadow. The rocks of the land break up, their parts are distributed by the different streams, and in the main carried to the sea; and in or along the sea they are again prepared for new rock-making. It is there that one could almost say rocks grew, but the growing is very different from what we habitually understand by that term.

Our sandstone is then of marine origin, since it is made up of the oceanic sands; and these sands must have been derived from the destruction of such rocks as contained the elements of true sand, possibly some more ancient sandstones, or even granites. In stating that it is of marine origin, we only say what is true of by far the greater number of rocks of the earth. It is a fact that some (and even sandstones) have been formed in the fresh-waters of the land, in lake-basins, and in river courses; such are designated "fresh-water rocks" (fresh-water sandstones, etc.). We shall learn later how to distinguish between the two classes.

Limestones and Marbles. — Hardly less common than sandstone, and in many places much more abundant than it, are the limestones. Marble, which is only a crystalline form of limestone, is known to us all in the many marble buildings of our cities, in the white, yellow, red, blue, and black mantels of our parlors, in table-tops, front-door steps, window-sills, etc. A piece of limestone or marble examined in the manner of our sandstone shows it to be a much softer rock; it cuts readily with a knife, without a grating sound; and if a chip is placed between the teeth it can be easily powdered up, and there is none of that unpleasant gritty feel which we have associated with the biting of sandstone. Some forms of limestone are, in fact, naturally "powdery;" such is common chalk.

In all three the substance is a chemical combination of carbonic-acid — the gas which is familiar to you in the fizz of soda-water — and lime. Put a little of your material in some strong acid, and you will presently note tiny bubbles rising to the surface; these are bubbles of carbonic-acid gas, which have been liberated through the action of the stronger acid. Your rock has been broken up ("dissociated") by the action of the acid; a part of it has disappeared as gas, while the rest, the lime, has been taken up in solution by the liquid acid itself. Were we to apply the same test to the shells of the oyster, the clam, the snail, or the delicate tracery of coral which rests on our mantel, we should obtain a like result; for, in fact, their substance is the substance of limestone and marble, and nothing more. How often have you looked at a polished marble table-top, or at a mantel, and remarked the curious figures which appear at the surface, and immediately suggest to you the shells of the sea-shore! Not knowing how limestone or marble is made up, many people believe these marks or figures to be the design of the builder or stone-cutter; but they are true shells, which ages ago belonged to living animals, and the whole mass together constitutes a *shelly limestone.* Many of the table-tops, more particularly in England, show plainly the impressions of corals, and hardly anything else; such are *coral limestones.* And there are many that are crammed full of the parts of a class of animals, distantly related to the starfishes, which are known as stone-lilies or crinoids; they were, in past ages of the earth's history, exceedingly abundant, but to-day only linger on. Limestones made up of these parts are known as *crinoidal* limestones. (Plate 4, Fig. 3.)

Organic Nature of Limestones. — From the facts that we have here learned, the suspicion grows upon us that limestone or marble, no matter how it appears, — whether it shows the marks of animal existence or not, — is principally a make-up of the hard parts of various shell-fish, corals, etc., which lived at about the time that the rock was being formed. And so it really is. It was only the other day that, in one of our large cities, standing at the intersection of two streets in front of a row of houses that were then building, I noticed that the lower course of stone was of an unusually attractive bluish color; stepping up to it for a nearer study, I found, to my pleasure, that the whole mass was one dense accumulation of minute shells, corals and corallines, some of them so tiny that only with a strong pocket magnifier could the parts be clearly distinguished. They stood out in all directions, for the rock was rough-dressed, and not polished. In a cubic foot of the rock there must have been hundreds of thousands, perhaps millions, of these ancient or fossil remains. For one who had never seen anything of the kind before, there could be no more impressive lesson — to think of the billions and billions of life-forms that go to build up limestone rock!

The Obliteration of Organic Traces. — Unfortunately it is not in all limestones that we can distinguish the organic parts which enter into their construction. In some, these parts are so minute that they readily escape the eye; in others, only the microscope can determine their presence; and in still others, the microscope, as well as the unassisted eye, fails to make out anything. In many such cases, and probably in the greater number of them, we are right in assuming that the animal traces did at one time exist; but, in the long course of changes through which the rock has passed since it was first formed, the marks have become obliterated. Just as in the living animal the life can be crushed out of it, so with these harder parts, they have been crushed out of recognition. The pressures to which the rock has been subjected, the chemical and physical changes that have taken place within it, have been sufficient to destroy the final traces. Probably by far the greater part of the massive limestones and marbles which crop out in our quarries, which make up giant mountains, has been built up by inhabitants of the sea, — the shell-fish, corals, etc. Strange as this may sound, it yet appears to be the case; and if it is true, then wherever we have marine limestones to-day we have had the sea at an earlier day occupying the same position.

Coquina Rock. — Most limestones have in their construction, in addition to the animal parts which strictly build them up, a binding cement of lime. Along the sea-shore, where shells are plentiful, we not infrequently find a number of these stuck together, and so firmly that it is impossible to separate them without breaking. There is no more interesting rock than that which is to-day forming along the Florida coast — the so-called *coquina;* it is used in the construction of many of the southern buildings, especially of the humbler kinds, and consists of coarse shell fragments, held together by nature's cement, the carbonate of lime. It shows so plainly how it is made up, that it reads for itself a complete chapter in limestone construction. (Plate 4, Fig. 2.)

Fresh-water limestones are not very generally of great extent. They are built up of the shells of animals that inhabit the fresh waters, lakes and rivers, and whose forms it is not difficult to distinguish from those which belong to the waters of the ocean. In a subsequent lesson we shall study another type of limestones, — the stalactites and stalagmites of caves.

Chalk. — This material does not differ greatly from ordinary fine-grained limestones, except that it is soft and powdery, and for this reason well adapts itself to writing purposes. It is of the class which geologists frequently designate as "earthy limestones," and before an acid it behaves like almost every other form of limestone. It was a happy inspiration which prompted a distinguished naturalist to put a morsel of it, well powdered, in the field of his microscope: he saw the greater part of the mass broken up into a multitude of tiny shells, some of them so minute as entirely to escape detection by the naked eye. Some of them, again, were about the size of a grain of pepper; others perhaps of the size of a pin's head, and not many larger. They are all of them remains of very nearly the lowliest of organisms — organisms which, while they have hard parts, are practically destitute of organs. They have no blood system, no nerve system, and no true muscular system. They have neither head nor stomach, nor any internal support of any kind. But, despite these deficiencies, they grow on, develop, and reproduce like all other animals, except in a somewhat different manner, and seemingly go through the entire cycle of existence. Naturalists call them *Foraminifera*, meaning pore-bearers, from the number of minute openings or pores which their shells contain. Through these openings, in the living state, the animal protrudes delicate processes of the body, which help to propel it about, and probably bring to it a certain amount of its food supply.

Oceanic Ooze; Globigerina Ooze. — For our present purposes it is sufficient to know that, with one or two exceptions, all the animals of this class to-day inhabit the ocean, where they are so numerous, especially the kind known as *Globigerina* (the "globe-bearer"), that their dead shells, falling to the bottom, make the greater part of a whitish or gray mud-paste which is forming there. This Globigerina mud, or "ooze," which contains parts of many other animals, such as the teeth of sharks, the bones of whales, etc., follows the floor of the sea to a depth of about 15,000 feet; it has been accumulating through a long period, and how thick or how deep it is, nobody knows. It so happens that just this form of Globigerina is also about the most abundant of the organisms in chalk; therefore, from this and a number of other circumstances, we conclude that the great chalk deposits of the globe, like those which extend almost continuously from the picturesque white cliffs of England and France to and through Russia, represent an ancient sea-bottom very much like that which is found to-day in the deep ocean, — perhaps not extending to quite 12,000 or 15,000 feet, but almost certainly to 6,000 or 8,000 feet.

When we speak of chalk, we refer to the article that is fresh from the chalk cliffs, and not to the scratchy substance which so frequently and so obstinately declines to leave its mark on the blackboard. Many of our "chalk" sticks are only a cheap artificial compound of sulphuric acid and lime, — a spurious gypsum.

Flags, Shales, and Slates. — We often find that the sticky and disagreeable mud-flats of the ocean front, which perhaps follow the sands and pebbles, "cake" hard in dry or hot weather. Frequently have we attempted to cross one, perhaps for no other purpose than to see how well it would stand our weight; and often have we exclaimed that it was as "hard as a rock." When we said this, we were saying something that was not far from the truth; for, in fact, this same mud is making rock. Hundreds of thousands of feet in thickness of rock that appears in our quarries and in the mountain sides are merely compacted muds, — the sea-fronts or sea-bottoms of ancient times. Such is the greater number of the gray and blue *flagging* stones of our street sidewalks, the black writing-slates, the green, red, and black roofing tile-stones, etc. Some of these rocks are known to the geologist as *shales*, because they shale off in slabs of regular and not very great thickness; it is to the thinner plates that the name of slate is given. So perfectly have the old ocean muds retained their original characters, that on many of them we still see the ripple-marks which were carved on them when they were yet a part of the beach; others have sun-cracks, and some the pits which were impressed into them by the falling drops of rain. Here and there we can trace the burrow of the ancient worm, or the tracery which has been left by the decaying sea-weed. And yet all these marks and impressions may belong to a period removed millions of years from us!

The muds are brought to the ocean principally in the discharge of the great rivers, — rivers whose basins cover much disintegrated rock, and where there is a good supply of loose soil. Indeed, soil is frequently decomposed shale and flag, the hard rock once more going back to the condition of mud. Elsewhere it is formed from the destruction of several other kinds of rock, the granites, sandstones, etc.

Granite. — Of the many useful rocks that are employed in the arts, none perhaps is more useful than granite, and there is none that equals it in beauty. From the most ancient times to the present it has been considered preëminently *the* building-stone; and if it has its defects, it has certain good qualities which no other rock has. Some people know granite only when it is gray, others only when it is red; and they seem to be ignorant of the fact that it can be of almost any color, the color depending chiefly upon the characteristics of one of its several constituents.

Take up the first piece of really good granite that you come across, and examine it. You find it to be a coarse-grained rock, with particles which it is not difficult to recognize as belonging to at least three distinct mineral species. One of these is familiar to everyone as *mica*, the mineral that is often wrongly called "isinglass." It occurs in gray or blackish shining plates, which the blade of a knife can easily separate into thin seams. Wherever granite occurs in the field, particles of this shining silvery mineral will be found scattered about in the dust or sand, particles from the rock's disintegration.

A second mineral in granite is the gray or bluish *quartz;* it has a dull, glassy appearance, cannot be scratched with the knife, and always breaks across with irregular surfaces. It is the substance which we have already learned to recognize in sea-sand; and from it, indeed, much of the sea-sand is derived. The third mineral constituent, known as *feldspar*, is that which generally determines the color of the granite; it may of itself be green, yellow, blue, or red, and as such it may give these colors to the rock. Otherwise in most cases it can easily be distinguished from quartz by its pearly lustre, by being somewhat scratchable with the knife, and by breaking more nearly in flattened surfaces. With these three substances in its composition, a typical granite is built up. (Plate 3, Fig. 1.)

Distinct Types of Granite. — There are granites which contain certain additional minerals scattered about in their mass, — thus, *tourmaline granite* contains the mineral tourmaline; *garnetiferous granite*, the mineral familiar to all as garnet, and so forth. But these do not concern us at this time. One mineral there is, however, which is so often and so closely associated with the quartz, feldspar, and mica in the granite as to make it almost as much a part of the rock as the rest; this is the black or greenish-black *hornblende*, small flakes of which are often mistaken for black mica. Its great hardness, and the fact that it does not separate into thin sheets, ought readily to distinguish it. When the hornblende is present in large quantities, it makes *hornblendic granite*. At times it not only replaces the mica, but also the quartz; the granitic rock is then generally known as *syenite*. But whether syenite, hornblendic granite, or granite proper, the rock has much the same habit. It is a crystalline or semi-crystalline aggregation of mineral particles, which may be either coarsely large or minutely fine, making coarse-grained, fine-grained, and intermediate-grained granites. Sometimes the individual elements may be several inches across, at other times they are so minute as to be barely recognizable by the unassisted eye. In one class of granites the feldspars have the form of true crystals, and some of these are scattered about with more or less regularity through the rock. Such granites are known as *porphyritic* granites, or simply as *porphyries*.

Origin of Granite. — The fact has long been known that the cores or deep interiors of many of the biggest mountains are constituted of granite; hence this rock has frequently been looked upon as the foundation-stone of the earth. It has been supposed to be the oldest of all rocks, to have been the first to form when the earth was still in a semi-gaseous or half nebulous condition, and to have formed through the action of intense heat and under great pressure. Just how it was made no one could know, and not much more do we know to-day. There is one fact, however, which appears to be almost certain; and that is, that in the making of most granites a very high degree of heat was largely concerned. In the early period of the earth's history there was such a heat, and it is perhaps not surprising that so much of the granite should belong to this ancient time. But even to-day, from the molten material that is thrown out by volcanoes, granite is sometimes formed, so that we have the evidence before us of how at least some of the rock is made.

Igneous and Aqueous Rocks; Plutonic Rocks. — The fact that some rocks require for their making the action of heat, while others need water, has led geologists to subdivide the entire series into two great classes, — the igneous rocks and the aqueous rocks. Granite and its allies belong to the first series, and the sandstones, limestones, and shales to the latter. Again, for convenience, we often subdivide the igneous rocks themselves into two series, — such as solidify on cooling from a molten condition on the free surface of the earth, like the lavas of volcanoes; and others which harden under pressure within the earth's interior, like the granites. The former are designated igneous rocks proper, and the latter, from their sharing the realm of the Roman god Pluto, plutonic.

Gneiss. — There is a rock which in many ways so nearly resembles, and has so much the habit of granite, that by persons who are not geologists it is frequently mistaken for it. I well remember how, in my younger days of studentship, I was puzzled to tell this *gneiss* from granite; and, if candor compels me to tell the truth, my mind even to-day is not always free in its judgment. Both rocks have generally identical mineral constituents, and both have very nearly the same chemical constitution. An easily discerned difference can be found only in what might be called "typical" gneiss; there it will be seen that the different mineral species of the rock,—quartz, feldspar, and mica (or hornblende in place of mica),—instead of being promiscuously thrown about in their arrangement, are disposed in more or less regular lines or bands, which give a "foliated" (and not a "granitic") appearance to the mass. Here, so far as distinction is concerned, we are on safe ground. Oftentimes, however, the banding or foliation becomes obscured and irregular, and we approach more and more the structure that belongs to granite. Finally we reach the point where it becomes all but impossible to distinguish between the two, and where one might with equal propriety speak of a granite as of a gneiss. (Plate 3, Fig. 2.)

Origin of Gneiss.—Long before the days of my geological apprenticeship the masters of the science had discussed the possible origin and method of formation of gneiss, and the discussion continues to this day. Some have argued, as concerning granite, that it was the foundation-stone of the earth; others, that it was merely an oceanic mud like our shales, which, through some chemico-physical action, had been transformed or metamorphosed into the peculiar rock which we recognize to-day. Volumes have been filled with eloquent dissertations on this subject, volumes will probably be filled in the same way in the future; but at present almost all that we can say with an approach to certainty is, that gneiss is generally — almost invariably — a very ancient rock, and perhaps no longer made; it has often the habit of granite, into which it seems to pass by insensible gradations; it has often the habit of the ordinary aqueous rocks, of which it may be only a physical or chemical transformation or metamorphism (hence *metamorphic rock*).

It occurs in masses thousands of feet in thickness, and generally represents the most ancient parts of the continents that have been preserved to us.

Mica Schists and other Schists. — In some rocks that resemble gneiss the mica element is so largely developed that it gives to them their distinctive character. The mineral itself occurs in fairly large plates; and these, by their ready division, tend to "schist," or break the rock into thin plates — schists. Hence the rock is known as *mica schist;* generally it is only an alternation of quartz particles and mica scales or plates. Other rocks breaking in much the same way, but with different minerals supplanting the mica, are the *chlorite-schists*, *hornblende-schists*, etc. Much of the obscurity which still attaches to the origin of gneiss also belongs to mica schist; and the two are not only closely associated with one another, but seemingly very closely interrelated.

CHAPTER III.

WHAT ROCKS LOOK LIKE IN THE FIELD.

ONE often hears the remark: I should like to study geology if I only knew how to tell the rocks. This is not a difficult task, for the kinds of rocks that one ordinarily meets with are not numerous. We have described the greater number, and many others are merely important varieties or close neighbors of these. So far as distinguishing them is concerned, we have only to find out to what broad group a given specimen belongs through a common-sense analysis. For example, a limestone is a moderately hard rock, which can be easily scratched or cut with the sharp edge of a knife, and which, when particles of it are put in a strong acid (nitric, sulphuric, etc.), gives out tiny bubbles of gas, and disappears. If a cold acid will not produce this effect, the acid warmed up almost invariably will. Marble acts like limestone, and only differs from it in having its mass crystalline or sub-crystalline in appearance and structure.

A shale or flag is also a rock of moderate hardness, which is sometimes not easily distinguishable from limestone; but it does not give the acid test (that is to say, it does not "effervesce"). The difference is thus clear. Occasionally it holds lime within it, and then bubbles of gas are given off; but the process is a feeble one as compared with the action on limestones. Everyone knows slate; it is a thin shale, as is also natural roofing-tile or tile-stone.

A sandstone can be recognized easily by its granular or grainy structure, the irregular sand particles, large or small, coming roughly to the surface. It is a rock that scratches hard, and gives out a harsh grating sound when the knife-blade is pulled across it. Acid has little or no effect upon it. Sometimes the sand (quartz) particles have been fused or melted together, so that they hardly appear distinct to the eye; the rock is then known as quartz rock or *quartzite*, — a tough substance, on which the knife-blade hardly makes an impression.

The granites we recognize easily through the few, but very distinct, characters which were indicated in the last chapter. From them the gneisses differ in the banded or foliated arrangement of the several mineral elements, — the quartz, feldspar, and mica, or hornblende, — and the various schists, by their scaly or schistic structure.

In the few rocks here indicated we have probably the materials of nine-tenths of all the known rocks that go to make up the earth's crust. There are not those hundreds and thousands that some believe to exist, nor is there any real difficulty in finding out what an average rock is when one quietly analyzes it by the few tests that have been given, — of the eye, the knife-blade, and the acid, and with them a generous admixture of common-sense. But the important facts of geology are not those that tell us what a rock is, but what the rock itself teaches.

Fossil Imprints in the Rock; Ripples. — In a quarry of red sandstone and shale which lies at a little distance from the road over which my calling carries me, there is what quarrymen and geologists call a big "exposure" of rock. The rock is piled up, bed upon bed, in horizontal or nearly horizontal layers, perhaps to a height of seventy-five or a hundred feet. With the good-will of my workingmen friends I have sat for hours in the pit by the side of the hoisting derrick, eagerly watching the fresh faces of the rocks that were being pulled out, and hoping for something new. Time and time again had I searched and searched in vain; but to him who looks long enough, something is almost sure to come. And so it was when one day the rock split, and disclosed on its inner face beautifully formed ripple-marks. There were the unmistakable impressions of moving water made when the rock was still soft — a mud. Across the ripple-marks, and completely obliterating some of them, was a number of distinct impressions of the feet of some animal that chanced to find its way to this mud, and across which it manifestly walked. Time had effected wonderful changes. The soft mud, with its impressions and carvings, was now hard rock, and what was once the free surface was now buried about fifty feet by other rock that had accumulated over it. This being an early discovery of my studentship, I wondered long how a surface of this kind could be buried by other rock. Then the thought came to me that, if the ripple-marked mud was the ancient bank of a river, it might easily have been covered, time after time, by the muddy floods of that river; that the rivers themselves often raise their beds by heaping mud and

Plate 5.

1.

2.

ROCK IMPRESSIONS.

1. Ancient ripples in rock of Silurian age.
2. A block of Triassic shale, with sun-cracks and footprints of a giant amphibian (salamandroid?).

Plate 6.

ROCK IMPRESSIONS.

A slab of Triassic shale, showing three-toed and bird-like track of a reptile. The pits scattered over the surface are the impressions of raindrops — the evidence of rain falling at this early period.

sand upon them, and thus flood upon flood would build up rock upon rock. Again, if the ripple-marked rock represented an ancient oceanic shore-mud, it might have been swept over by fresh oceanic sands and muds when the water rose above it; but a great thickness of covering could only be made when, for some reason or other, the waters of the sea rose very much higher than the usual high-water mark, or the land sunk beneath them. Both of these conditions, as we shall learn later on, took place repeatedly in the course of the earth's history. (Plate 5, Figs. 1 and 2.)

Footprints and Raindrops in the Sands of Time. — Years later, in wandering through one of the large museums of our country, I stumbled upon a big block of the same kind of stone, — the ripple-marks were as distinct as upon my own specimen, and the footprints, if anything, still more distinct. But the label attached to the specimen stated that the whole surface was pitted with raindrop impressions, — "fossil raindrops," — and there they really were, the evidence forged in the rock that rain fell over a certain mud-flat millions of years ago! On looking attentively at the rock-surface, it became manifest that the animal which walked over the rock had been caught in this rain; for many of the raindrop impressions were in the animal's footprints, and many others were obliterated by them. Here was a history of the times complete in itself, and inscribed in characters far more durable than any that man himself has been able to manufacture. (Plate 6.)

What Rock-Strata Signify. — We have now learned from our quarry that the different beds of rock which lie one on top of the other are the ancient muds or sands that have been laid down peacefully by overflows of river or ocean waters. Technically, these beds are known as *strata* (singular *stratum*, which means a layer or bed), and all rocks that show in themselves this construction of strata are called *stratified* rocks. As an alternative, they are frequently spoken of as *sedimentary* rocks, inasmuch as they represent the sediments of ancient waters, whatever the kind of water may have been. Where the strata occur in horizontal or nearly horizontal lines, it is a proof that there has been no forcible disturbance in the region occupied by them, the rock-beds being very nearly or exactly in the positions in which the muds or sands were originally laid down. Sediments in this position are found in many parts of our continent measuring thousands of feet in thickness. (Plate 7, Fig. 1.)

Disturbed Rock-Masses. — Rock-strata do not always lie horizontally. Sometimes they are gently arched, at other times very strongly so. In such cases there has manifestly been some disturbance in the earth's crust since the rocks were formed, as they never could have been deposited by water in irregular positions of this kind. Indeed, we not infrequently find the rock, be it limestone, shale, or sandstone, standing with the beds on end, or vertically, showing that they had been turned over on themselves fully ninety degrees. In some cases the upturning has gone still farther, and completely reversed the rock; and finally there are not a few places where the strata have been so turned, twisted, and folded upon themselves that it becomes a matter of difficulty to determine their true relationships. We ask ourselves the question: What kind of a disturbance could have brought this about? Almost the only answer that can be given to this question is, that something caused the earth to pull and push, and that the rock gave way under the strain that was imposed upon it. Probably in most cases the movement was brought about by a general contraction of the earth's mass, due to its continued cooling. When an autumn apple shrivels through exposure to cold, it pulls itself together, and with it goes the puckering skin. The same thing must have repeatedly happened with the "skin" of the earth, the rock-crust, and hence the endless puckerings and foldings. (Plates 8–11.)

Rock-Folding. — It is at first difficult to realize the extent to which rocks have been folded. Often, when we find them lying in apparently horizontal positions, the horizontality may only be the expression of a very flat giant curve or arch, whose span covers perhaps miles of country. Also, when the beds stand vertically, they are usually only part of great arches or sharp zigzag folds, whose tops have been carried away, in the course of ages, through decay and the destroying power of water.

But we can well turn from the contemplation of the grand to the study of the insignificant. If rocks have been folded and twisted upon themselves on a most gigantic scale, it is equally true that often they have been folded so minutely as to show all the evidences of disturbance in hand specimens. I have a slab of talc or soapstone which measures only a few inches across, and yet from its many puckerings it resembles a piece of corrugated iron. In a specimen of gneiss the foldings can be followed down to the dimensions of a quarter of an inch, or even less. It is no easy matter to conceive at first sight how hard and solid rock can be folded in this way, but that it does so fold is beyond question. More than this, even the shells and skeletons that are enclosed by the rock as fossil remains partake of the general disturbances. They are often pulled out, twisted, or otherwise deformed, and yet show no signs of breakage. It seems to be a fact that any substance, no matter how firm or rigid it may be, no matter how fragile, can be deformed through long-continued pressure. Arctic travellers have frequently called attention to the fact that great flat cakes of ice will in course of time sag and warp through their own weight, curving under in the most interesting manner; and in the possession of one of our institutions of learning is a large, old-fashioned tombstone, which has "hollowed" quite extensively through sagging between the four stone posts which held up the corners. That the movements in the earth's crust which caused rock deformation were of the slow and continuous kind is borne out by much evidence.

The Positions Occupied by Rocks; Dip. — The knowledge that we have just acquired permits us easily to appreciate the different positions which rocks occupy in the field, in the quarry, and in the mountain side. The horizontal, the vertical, the steeply inclined, and the twisted and folded are merely the links of a single chain, and each for itself represents a condition that was imposed upon the rock-mass. Quarrymen and geologists use a convenient word to indicate a departure from the horizontal position; they say that the rock "dips." The steepness or amount of *dip*, by

Plate 7.

1.

2.

THE POSITIONS OF ROCK-MASSES.

1. Horizontal strata, near Quebec, Canada.
2. Outcrop of coal in the Pennsylvania region; the strata appear on their edges horizontal; but the oblique arrow indicates the actual face of the beds, showing that they are steeply inclined.

Plate 8.

1.

2.

THE POSITIONS OF ROCK-MASSES.

1. Steeply inclined limestone strata, in Potts's Quarry, near Philadelphia; the "strike" and "dip" are both indicated by the arrows.
2. Steeply inclined strata of limestone along the Schuylkill River.

which we mean the extent of departure from the normal horizontal line, is measured by degrees; thus we say the rocks dip 45°, or 30°, or 25°, as the case may be. When the beds stand vertically they occupy the position of 90° dip. The direction *toward* which the rock drops or dips is determined by the compass; thus we say, geographically, the rock dips to the north-west, or to the south-west, etc., by which we mean that the slope of the beds points in those directions. (Plate 8.)

CHAPTER IV.

WHAT A MOUNTAIN TEACHES.

IF in your rambles through a mountain region you have a will strong enough to turn the mind at times from the contemplation of the grandeur of scenery to a study of that which makes up scenery, you will easily ascertain three facts as the outcome of your investigations: 1, that, with comparatively few exceptions, mountains always occur in disturbed areas of the earth's crust; 2, that, as a necessary consequence, their rocks are badly tilted, curved, folded, and broken; and 3, that these twists, curves, and folds are merely an amplification of the similar conditions which we have already learned to know in the rocks of the field and in hand specimens. How often have we looked with wondering eyes upon those majestic Alpine peaks, towering perhaps two or three miles into the air, whose naked rocks, folded and zigzagged upon themselves, plainly record the history of the strife and struggle that are involved in the process of mountain-making. Even to-day, long after Nature has worked hard to efface what she has reared up, many mountains retain in their contours nearly the exact outlines which were given to them when the rocks were first thrown up to aid in their construction; others are merely wrecks of former greatness, monuments to the destroying hand of Time.

How Mountains may be formed. — Perhaps the simplest mountain that we can picture to ourselves as having been formed through a contraction of the earth's mass is a single fold of rock-strata. If you place on the table a number of napkins or table-cloths, one upon another, and push gently from the opposite sides, you are likely to force up a fold of this kind. Your pushing is only the equivalent of the pulling in of the earth's crust, and the napkins may be taken to be the rock-strata. If you continue pushing, you will probably raise up a number of distinct folds running parallel to one another. So, in the case of the earth's crust, continued or excessive strain has reared up parallel folds of rock, and these are the backbones of mountain chains.

Mountains of Simple Folding; Strike, Anticlines, Synclines. — Many a freshly born mountain chain had this simple structure of parallel arched ridges and separating longitudinal troughs or "valleys," and there are some which even to-day retain it. Our own Alleghany Mountains had it once, and so did the Jura Mountains of France and Switzerland. Were a cut to be made clean across the trend, or *strike*, of such a series of mountain backbones, it would show the rocks arching beautifully upward to form the mountains, and falling basin-like beneath the valleys; geologists speak of the upward falling arches as *anticlines*, and of the descending ones as *synclines*. (Plates 9, 50, and 51.)

Had all mountain chains the simple structure that has here been described, there would be little difficulty in reading their full history. Unfortunately, in geology, complexity, rather than simplicity, is the rule; and many a hard nut has to be cracked before we can satisfactorily answer to ourselves what appears to be the simplest of questions. Especially complex are the conditions that are presented by mountain masses, and frequently years of close and continuous study are needed to make these conditions properly understood. It is not necessarily one disturbance alone which has made a mountain range or system; but more commonly a number of distinct disturbances have followed one another at irregular, and perhaps far-removed, periods of time. The mountain has had, so to say, several "makings," and with each of these the rocks have been further pushed, folded, and broken; the arrangement of the beds, or strata, may in this way become almost hopelessly intricate and confusing.

Overturnings and Mountain Travel ("Shearing").— In the work of compression and crushing, the beds have not infrequently been turned completely over upon themselves, so that bottom rocks have come to be located on top, and the top rocks at the bottom. Some notion of the intensity of this earth-strain may be had from the fact that certain mountain masses have been moved bodily miles from the positions which they had at one time occupied, and this movement has in some cases been over the tops of other mountains. Such "shearing" movements were involved in the making of the Scottish Highlands, in the Alps, etc. Of course all this was a slow process; ages may have been involved in the moving, as certainly they were required for the actual rearing of the mountains themselves. It was not the matter of a few years, but probably of hundreds, or even thousands, of years.

Dislocations; Faults.—All over the earth's surface,

Plate 9.

1.

2.

THE POSITIONS OF ROCK-MASSES.

1. An anticlinal arch near Hancock, Md.
2. A synclinal fold in the coal of the Hazleton basin, Pennsylvania.

Plate 10.

1.

2.

THE POSITIONS OF ROCK-MASSES.

1. Sharply folded strata of sandstone.
2. Sharply folded beds of limestone passing into a "fault," or fracture with displacement.

or through the crust, there are evidences of prodigious breaks across the rocks, some of these running across thousands of feet of rock thickness in an almost direct course. At times these rock fractures make no displacement in the position of the beds which they traverse; at other times they throw them to one side or another, sometimes elevating the strata on one side of the break, sometimes dropping them. Breakages of this kind are known to the geologist as *faults*, because they have "faulted" the rock. There is hardly a mountain mass that does not exhibit within itself the evidence of breakages and faults; they are so abundant at times that the rock may be said to be completely *parcelled* up by them. Coal-miners only too well know what a disjointed material — the coal and adjacent shale — they have to deal with in their underground workings. Big faults and little faults (these sometimes so small as to measure only a few inches) crowd in so rapidly as to thwart the operation of mining almost continuously. There is in my possession a section of cobblestone which shows it to have been broken across in not less than five places; and yet the same kind of force which produced the breakages must have helped at another time to unite the separate pieces, for the cobblestone (showing clearly the lines of fracture) is one single piece again. (Plates 10 and 51.)

Fallen Blocks of the Crust; Continental Buttresses ("Horsts"). — The further and more carefully we carry the eye through the testimony of the rocks, the more clear does it become that at least the superficial part of our planet has undergone repeated breakages, and that these are continuing well on into our own day. That which we have habitually called the "solid crust" is being irregularly dismembered, or sectioned up into elevated "bosses" and fallen "troughs." Parts of what had at one time been more or less continuous land-areas now lie buried beneath the sea, having fallen bodily beneath the level of the oceanic waters. The basin of the Mediterranean is one of these fallen blocks of the earth; the Gulf of Mexico is probably another; and not unlikely a large part of the Atlantic itself is a third, or, in fact, several blocks which have fallen one after the other. Between the eastern coast of the continent of Asia and the outlying volcanic islands — Kurile, Japan, Loo-Choo, etc. — is a series of half land-locked waters, the Japanese, Yellow, and Kamchatka Seas, which occupy positions that were formerly incorporated with the dry land. In the same way the North Sea and the passageways leading from it to the open Atlantic are located on subsided or broken-through parts of the older continent of Europe.

In the heart of many of the countries which to-day smile peacefully beneath their seemingly quiescent conditions breakages are still continuing, just as they had been going on for ages in the past. France and Germany and Italy all show their broken parts — the buttresses (or *horsts*) — that have remained standing between the breaks and the deep depressions which mark the positions of the breaks themselves. The deep hollow of the Dead Sea basin, the narrow basin of the Red Sea, the trough of Lake Tanganyika in East-Central Africa, the Gulf of California, and even our own picturesque Yosemite Valley, are seemingly only subsided parts or blocks of continents.

Crustal Breakages and Mountain-making.—It is a significant fact that nearly all the great breakages of the crust stand in close relation with the making of mountains. Thus, the successive falls of the Mediterranean basin were associated with the rearing up of the Alps and Apennines; those of the Mexican and Caribbean basins with the mountain elevations which run in disjointed spots or lines (in olden times continuously) through the Lesser and Greater Antilles. Probably the side-pressure that was exerted by the fall was mainly instrumental in "squeezing" up the mountains, while the break itself was determined by a previously existing weakness in the crust. It is a long-continued and not sudden history that is read in those breakages, one that is measured not by years, but by centuries. And yet we know that even in our own times, following or accompanying earthquakes, parts of the land-surface have been lowered, and lowered suddenly, through a half-score of feet or more. Only so recently as the events of 1893 in Phocis, Greece, have we had proof of this; water-channels were at that time measurably deepened, and peninsulas existing as such for centuries were broken up into islands. The beautiful islands of modern and ancient Greece seem only to be the separated parts of an old Greece which formerly extended far into what is now the Mediterranean basin.

THE MODELLING OF MOUNTAINS AND THE MAKING OF SCENERY; THE WORK OF WATER.

It has not happened to the eye of existing man to see any large mountain newly formed. The mountains of to-day are, generally speaking, ancient; from the point of view of the geologist some are very ancient, others are comparatively modern, and many are decidedly new. Of the last-mentioned we may mention the Alps and Himalayas; of the first, the Adirondacks and White Mountains; and among the intermediate group, although removed from us by certainly a few millions of years, may perhaps be classed the major part of the Alleghanies. But whether old or new, all have suffered changes that have been brought to them by the hand of time, — the result of the work of internal decay, and of the ceaseless destruction that comes from the attack of outside forces.

How Water Works. — When after a heavy rain you wander out into the freshly washed country, you cannot fail to observe how muddy the numerous streams are. They are carrying away the materials from the solid rock, and to that extent are they helping to shape the landscape. Every stream, no matter how insignificant it may appear, does some work; and the total of all streams, when their efficiency is summed up, is prodigious. But it all goes back to the tiny drops of water that make the streams — the drops of rain or the flakes of snow. In our own gravel-walk we see what the raindrops do directly. They "pound" out the small grains of sand that lie between the pebbles, and loosen the whole for the action of running water. Under the drip of your drain-pipe the same thing is taking place, only perhaps in a more systematic way. Drop after drop there falls into nearly the same place, so that a system of earth modelling — a true sculpture — is being carved out. We see tiny pillars of sand

Plate 11.

1.

2.

THE POSITIONS OF ROCK-MASSES.

1. Convoluted gneiss of the Wissahickon Valley, Pa.

2. Steeply pitching beds of hyro-mica schist, at West Conshohocken, Pa., showing surface overturn, or "creep."

Plate 12.

1.

2.

THE POSITIONS OF ROCK-MASSES.

1. The limestone of the Schuylkill Valley, Pa.; the horizontal arrow indicates the line of strike, the oblique one, the dip (30 degrees).
2. Folded gneiss of Philadelphia, with uncomformable clays (U) resting on top.

and gravel standing in the line of rain-furrows, many of them standing only because they have been protected from down-wash by a hard capping of gravel — their umbrella, as it were. How often, on marl or sand-heaps, have we picked off pebbles and shells from the tops of little pillars of earth — pillars that stood out from the general mass because, under protection of their own hard covers, they for a time successfully resisted the beating action of rain. This may appear a trivial lesson; but it is a key to the understanding of that which, developed on a gigantic scale, oftentimes inspires us with no less awe than wondrous admiration.

Earth Pillars and Monuments. — The great pillars of earth which, in parts of the Western United States, in Wyoming and Colorado, stand up by hundreds along the mountain sides and in the open valleys, many of them capped by bowlders which are carried seventy-five or a hundred feet above the general surface, are only an amplification of the tiny sand-pillars beneath the pebbles. They are monuments, and monuments on a most impressive scale, of the wearing action of water, and are the index that measures the amount of destructive work that has already been accomplished. To the tops of their highest points the general surface of the land at one time extended, and how much beyond cannot be told. Well do they carry, in their association of ideas, the name of "Monument Parks." The fantastic rocks, pillars, and needles that so picturesquely diversify the "Garden of the Gods," lying near to the foot-hills of the Rocky Mountains; the castle-like rock buttresses or "buttes" which grimly look down upon the sand-wastes of the western "bad-lands;" the "Pillars of Hercules," etc., that mark the entrances to many of the deep river gorges or cañons, — are only similar witnesses to the destroying power of falling and running water, — the monuments that reconstruct for our eyes the full landscape of which they now constitute lingering remnants. Before very long they, too, will have vanished; but for the moment they teach us the lesson of *aqueous erosion*, the extent to which the country has suffered through the eroding or wearing action of water. Hundreds of feet above the great plains of Wyoming, over which the railroad now courses to the Pacific, the old-time surface extended, as is evidenced by the monuments which stare at the traveller from either side of the road; but, unmindful and ignorant of the history which these great castellated buttresses record, the traveller glances at them merely from the standpoint of curiosity, or of simple wonderment at their grotesque and imposing forms. (Plates 13, 18, 19.)

Ravines, Gorges, Gulches. — Just as these huge towers and pillars are the counterpart of the small pillars that we have seen fashioned out of the surface of the marl-heap or in our gravel-walk, so are the deep ravines and gorges merely the counterparts of the insignificant waterways of rills and rivulets. What the small streams have done in a small way, the larger streams have done in a much larger way. They have cut deep and effective channels, some of which have broadened out into great open valleys, while others are still retained so narrowly compressed within their boundary walls that they present more the aspect of earth-rifts than anything else. Nearly all the structures that we recognize under the names of ravine, gulch, defile, gorge, clove, and cañon are merely the basins that have been hollowed out by running water, — the work of the carving tool that began its operations when solid rock first came into existence with the cooling of our planet, and will continue them so long as there is water on the surface of the globe and a sufficiency of moisture in the atmosphere.

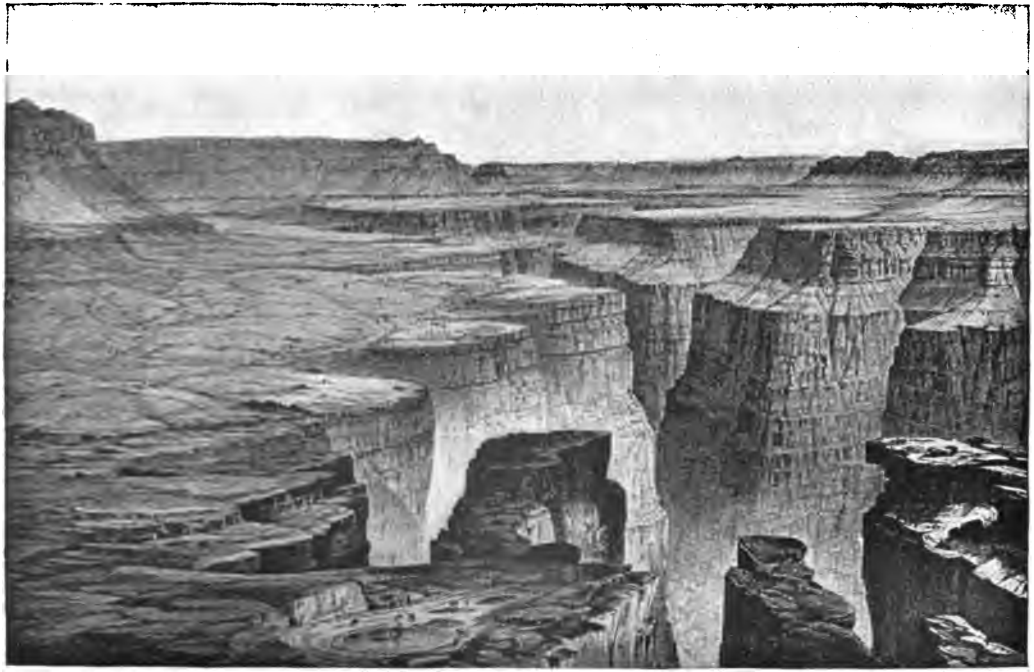
The Base-Level of Erosion; Peneplain. — The mind can well project itself into the future, and see the entire landscape worn down to a level so nearly uniform as to constitute one great flowing plain. Any large area that has been so washed down is described as having been worn to the *base-level of erosion*, or to that point where the main stream, as well as its tributaries, is so exceedingly sluggish as to be no longer able to carry on the course of destruction. This level is reached when the worn-down surface, or *peneplain*, has fallen very nearly to the level of the sea, below which there can be only exceptional erosion. Let us conceive that this level has, in one way or another, been elevated high above the sea; the waters of the land will then begin to cut their courses anew; fresh vigor has been given to them, and once more they work as in days of old. (Plate 17, Fig. 2.)

Cañons. — There is to be found on the surface of the earth no more imposing lesson teaching the destructive work of running water than is furnished by the deep river-channels of the Western United States, — known in the language of the country as cañons, — which in sharp cuts, usually of a terrace-form, descend thousands of feet through the solid rock, whether it be sandstone, limestone, or granite. For ages the waters have been cutting, and are still cutting to-day, slowly but steadily working down to that level — the level of the sea — where there is no longer a fall, and when of necessity this kind of work must cease. If the land should progressively rise as the cutting continues, then will the process of destruction also continue, with the end always pointing to the day when the channel will have been worked down to the sea-level. The Grand Cañon of the Colorado, which in many respects is the most imposing of all structures of its kind, has a length of more than 200 miles, with a depth, in its deepest parts, of more than 7,000 feet. At its top it opens out to a width of from eight to fifteen miles; but at the bottom, where the turbulent Colorado River tumbles through its bowldery course, it becomes so narrow that in many places even a foot-passage on either side of the stream is hardly possible. The same general characteristics that are found in the Colorado Cañon belong as well to its numerous tributaries, and in some the sharpness of the cut is even more emphasized. In the cañon of the Virgin River, the rocky walls are really the walls of a cleft so narrow and so profound that the rays of the sun hardly penetrate to the bottom. The Royal Gorge of the Arkansas is of a similar nature, — a narrow chasm cut through granite walls which plunge down precipitously to a depth of 2,000 and 2,600 feet. It is in truth possible, and even probable, that some of the narrower cañons, like the one of the Arkansas, may have been initially formed by a splitting open of the rock-masses through which the rivers now force their way; but certainly the major cañons owe their

Plate 13.

THE CAÑON OF THE ARKANSAS. — "ROYAL GORGE."

Plate 14.



RIVER EROSION.

The Grand Cañon of the Colorado, showing the deep cut through thousands of feet of rock-strata, and the fragments of the former continuous surface of the plateau where it is now cut apart.

existence almost entirely to the work of running water. (Plates 13, 14.)

Old and New Features in a Landscape; Valleys. — It has been said that ages were involved in the cutting of the cañons, and yet the geologist looks upon them as young or youthful features in the landscape; we know in a general way the limit of age, for they cannot be older than the top rock in which they began their work, and this rock is a comparatively new one in the construction of the earth. Perhaps a hundred thousand years, or two hundred thousand years, cover the full period of their existence. We have cañons in other parts of the world, — the gorge of the Niagara River is one, — but in many we hardly recognize the features that belong to the western type. The work of time has expanded their measure, the steep walls have gradually faded away under the effects of atmospheric erosion; other streams have worked their way in and out; and, finally, in place of the narrow oppressive chasm, we have the genial and sunshiny open valley, — the valley with flowing outlines, the plain that has become suited to the wants of man, and productive in the development of nature's resources. In such we have "old" features in the landscape; for every landscape may be said to contain features that mark periods of youth, middle age, and maturity. (Plates 16, 17, 18.)

Mountain Valleys and the Conditions of Scenery. — Our study of the primitive mountain chain has clearly shown how, through a folding of the earth's crust, a number of parallel ridges may be formed, ridges that are separated by a parallel series of hollows or troughs. These hollows can justly be called *longitudinal valleys*, since they run longitudinally with the mountain backbones. But it is not often that one sees so simple an arrangement of parts in a mountain region. More commonly there is a bewildering assortment of mountain peaks, of disjointed mountain buttresses, of valleys running in one way and of valleys running in another way, some following closely the trend of the hills, — if any trend is at all discernible, — others cutting completely across it. We are in a true mountain wilderness, where the landscape owes much or most of its disturbing irregularities to the wash of water. From the first moment that mountain began to be mountain, the ceaseless energies of falling and running water began to destroy it; and it will be readily understood that the destruction or levelling down of any mountain, no matter how great, how majestic, or how imposing, is merely a matter of time. It is to this destruction, to the irregular manner in which the destruction is carried through, that we owe that diversity of form which in a landscape makes scenery. Without it there would be no peaks, pinnacles, or needles, no deep gorges or cañons; the cataract would be silent, and the whole landscape would wear a monotonous garb.

Transverse Valleys; Water-Gaps. — No one who has visited a mountain region can have failed to notice the numerous streams that go tumbling down the mountain sides. Some are truly insignificant, others are much more important; but one and all, whether large or small, are steadily eating their way back into the mountain core, gashing the steep slopes with so many distinct cuts or channels. And if the mountain is a simple ridge or backbone, what is being done on one

Plate 15.

1.

2.

THE WORK OF RIVERS.

1. River-cut across the mountains, Glenwood Springs, Col.
2. Gap of the Bow River, Alberta.

Plate 16.

1.

2.

THE WORK OF RIVERS.

1. Plain-making by a river; the Delaware above the Water Gap, Pa.
2. The course of the Grand River, region of the Yellowstone; the rocky eminence on the right is an "escarpment." Both rivers, in conjunction with atmospheric destruction, have formed broad, open plains.

side is almost certainly being done on the opposite. Some of the streams work faster than others; they have more volume of water, a steeper slope, and perhaps more crumbling rock to work through; while the less powerful ones have only succeeded in carving from the mountain side troughs or valleys of moderate extent, these may have gained to the very heart of the barrier, and perhaps cut it completely through and down. Then we should have a *transverse* (cut or) *valley* formed, and unquestionably many of the structures of to-day which hold this relation have been formed in this manner. Who can look deeply into the gorges and "cloves" of the beautiful Catskill region without recognizing this condition! Some of them hang high up on the mountain slopes; others have been cut completely through, and take the drainage from the two sides of the mountain. The mountain has been "gapped." (Plate 15.)

The very much frequented summer locality in the State of Pennsylvania known as the Water Gap derives its name from the circumstance that the Delaware River at that point cuts its way transversely through the hard rock of the Kittatinny or Blue Mountains. When I first visited the locality I was impressed only with the beauty of its natural scenery, the rugged forest-covered cliffs, the placid river, and the smiling fields lying on either side of the gap. Later I wondered why the Delaware, which flowed so peacefully down the valley on the off-side of the gap, should have suddenly turned, and cut a channel through the mountains, instead of simply following their trend. This was a puzzle, and the like of it still puzzles geographers.

The Origin of Gaps. — The Water Gap is one of a numerous series of similar structures that are to be found in the mountains of the Eastern United States, and through which many of the larger rivers break their way to the sea. The Hudson River, for example, gaps the Highlands of the State of New York at West Point; the Lehigh gaps the Blue Mountains at the Lehigh Gap; the Susquehanna at several points the Alleghanies; while the Potomac breaks through the Blue Ridge at Harper's Ferry. These rivers have all taken to breaking their courses at one or more points where they approach the mountains, and they largely repeat the problem which is presented by the Delaware. We are probably not yet in a position fully to understand this action. In some cases, possibly, the trenched mountains were reared up by slow degrees in the path of the already existing rivers, which simply cut down as fast as elevation went up in front of them; in others the gaps may have been originally cut by streams other than those which now occupy them, — a preparation for occupancy, as it were; and in most instances, perhaps, the explanation is to be found in the simple fact that the contours of the country are not to-day what they were formerly, that the positions of present deep valleys are the positions that for ages were occupied by high plateaus and mountain masses, and that the channels were cut when the relations of mountain and valley were in a measure reversed. The Delaware, as we know from positive facts, at one time flowed on a high level, — a level above that of the mountain-top which is now cut through; and it was then, probably, that the cutting first began. In course of time open valleys have been carved out on either side of the mountain

Plate 17.

1.

2.

DENUDATION OF THE LAND-SURFACE.

1. A V-shaped valley in the Alps.
2. The Vale of Cashmere, an open plain of long-continued erosion; an upland peneplain.

Plate 18.

DENUDATION OF THE LAND-SURFACE.

An open, broadly U-shaped valley in the Utah Desert. The horizontal lines on the spur in the left middle-ground represent terrace-marks of the ancient river; the rock-prominences, or "buttes," are remnants of the old land-surface, standing as monuments of the erosion that it has suffered.

axis; and through and across them the river flows peacefully, reading its own history.

River Terraces. — Any one who has observantly travelled along gently meandering streams, especially along such as wind their courses through broad and open valleys, cannot fail to have noticed, now on one side of the river, then on the other, embankment-like elevations of the shore lines. A first impression of such an embankment frequently calls to mind the newly laid course of a railroad in construction, so similar does it appear, with its regularly planed and levelled top. For hundreds of feet at a time it may continue with engineering precision, then perhaps suddenly terminate with a break, again to resume its level farther on. A little careful thought suggests that these embankments represent in part the ancient flood-plain of the accompanying river, made when the waters rose regularly to a higher level than they rise at present. Even to-day the water occasionally covers the *terraces*, but the gradually lowering course leaves them more and more uncovered every year. A new flood-plain is being carved lower down, and along with it will appear the new river terrace. It is not an infrequent occurrence to see a number, four or five, of such river terraces, rising in strictly terrace-fashion one above the other, the upper one most removed from the confines of the present river, and of most ancient age. To it, possibly hundreds of feet above the existing water-surface, the river at one time reached; from it the stream has steadily receded downward to its present water-mark, constructing in its descent new flood-plains, and carving from them new terraces. Hence, in a series of river terraces, the lowest is always the one of newest date. (Plate 18.)

LAKE-BASINS AND MEADOW-LANDS.

To most persons a lake-basin is merely a great hollow, or trough, which has been worked out by the main stream that falls into it. Had the person holding such a notion put himself at the position where the said stream or river discharges into the lake, and carefully observed what was going on about him, he would in quick time have come to an altogether different conclusion. He would have noted that very little excavating was being done by the river; on the contrary, its only visible work was the filling in of the lake with the mud that it was carrying to it. Far into the basin is the mud being carried; and it stands to reason that in a certain time the entire hollow will be filled in, and the lake made dry. Nor is this an exceptional lake occurrence; it is the history of almost every similar structure that is to be found on the earth's surface.

The Silting of Rivers. — Rivers *fill up* the moment their velocities have been so reduced that they no longer are able to transport the materials that, as swiftly flowing bodies, they carry with them. Whether it be at the mouth of the river at sea-level, or in the more quiet lake basin, the same thing takes place; the river drops its sediment. Any one who has had the good fortune to stand at both ends of the lovely lake of Geneva, where the muddy Rhone enters on one side and leaves it, clear as crystal, on the opposite, will have immediately recognized the special "straining" quality of the lake; it relieves the river of its sedi-

Plate 19.

DENUDATION OF THE LAND-SURFACE.

The Giant's Club, near the Green River, Wyoming — a remnant of the old land-surface. The stratification and alternation of the beds are clearly defined.

Plate 20.

1.

2.

RECONSTRUCTION OF THE LAND-SURFACE.

1. The terraces, or former water-lines, of "Lake Bonneville," the ancient (now dry) basin of which the Great Salt Lake is a lingering fragment.
2. The valley of Engelberg, Switzerland, an old lake-basin laid dry.

ment, and by so doing fills itself up. All over the floor of this lake, as well as of all the other large lakes of Switzerland (or of the world), there is deposited a fine river-mud; and one need go but a short distance beyond the present confines of the water, to discover that some of the adjacent "land" country is merely a part of the ancient lake-bottom filled up and laid dry.

Meadow-Lands. — It is in this way that many of our most beautiful meadows and pasture-lands have been made to occupy the positions of formerly existing lakes; they are, indeed, those lakes filled in, and sometimes still carry with them the meandering stream which at one time was tributary to the lake. A wonderful change, one is prompted to exclaim; but it is one that had to come in the course of events. How pleasantly do we recall the scenery of those beautiful twin lakes of Switzerland, Thun and Brienz, and how frequently is the comparison made between the scenery of the one and the scenery of the other; but how rarely is it recognized that these two lakes were formerly one, and that the separation took place as the result of filling in. Few of the many who wander through the streets of charming Interlaken ponder the fact that they are walking over a part of the old lake of Thun-Brienz. (Plate 20, Fig. 2.)

Origin of Lake Basins; Crater Lakes; Glacial Lakes. If, then, lake basins are not cut out by moving water, but, on the contrary, are filled up by them, the inquiry naturally presents itself: How are such basins formed? Regretfully it must be said, there is as yet no definite answer to this question. Some lakes undoubtedly occupy natural hollows in the rock; others, similar hollows in deposits of gravel, sand, or mud; and many others, again, troughs that may have been made such through rock movements and dislocations. There are also lakes, like the lakes of Central and Southern Italy, and Crater Lake in Oregon, which occupy the crater hollows of formerly active volcanoes; and there are bodies of water which were formerly parts of the free ocean, but are now lakes through land-locking in one form or another. Such are the Lakes Como and Maggiore of North Italy, the Caspian and Aral of Eurasia. In these we still find evidences among the living animals of the ancient marine fauna. While the lakes of the classes here designated explain their own origins, it is doubtful if the greater number of the lakes, especially of the Northern Hemisphere, can be referred to such simple types of structure. Their occurrence is so markedly bound in with the evidences, in the regions which they occupy, of ice-movements, that by many geologists their basins are unhesitatingly ascribed to the scouring and gouging action of glaciers. And there is much to support this view. In the greater number of the regions where glaciers are to-day largely developed, we find an abundance of lakes; in nearly all regions where glaciers formerly existed, we also find lakes and hollowed rock-basins; and where there is no evidence of present or past glaciation we find but few and insignificant lakes, or only those whose basins can readily be explained on the assumption of rock dislocations. We shall learn more of this when studying glaciers.

Ancient Lake Basins; Lake Terraces. — Not far from the "City of the Saints," and high up on the slopes of the rugged mountains which descend to the shores of the Great Salt Lake, the eye sees long lines of seeming roadways winding around and about the rocky buttresses, sometimes in tiers of three, four, or five above one another. They run in almost absolutely horizontal courses, and look precisely like artificial constructions. When we mount to them we find that they are level planes, perhaps fifty, or a hundred, or even two hundred feet in width, which project like so many terraces from the face of the mountain. With the lesson of the river terraces in our mind, it is not difficult to recognize that these largely similar structures are exactly their counterpart, and represent the old levels which were formerly reached by the waters of the lake. Fully a thousand feet higher than to-day the waters of the lake, of which the Great Salt Lake is only a lingering fragment, sometime extended; at that time, and not very long ago geologically, the waters were still fresh, and they had a flowing outlet to the north-west. With its great depth this ancient lake — known to geologists as Lake Bonneville — covered an enormous area, perhaps ten times that which is covered by the modern shallow sea which remains in place of it. The saltiness came with the gradual desiccation or "drying out" of the waters, a condition which followed a gradual drying of the American climate itself, through what cause no one yet positively knows. The modern Great Salt Lake has no outlet, and the streams that flow into it are very nearly pure or fresh. Yet what little of salty material they carry in is all locked up to keep, and in this way it accumulates year by year. It is estimated that fully twenty thousand years were required to give to the lake the saltiness which it now has — a sixth by weight of the actual water itself. (Plate 20, Fig. 1.)

The Scenery of Lake-Shores. — So recent in time has been the existence of the old lake, that the shore-cliffs and caves which its ruffled waters carved are preserved with a freshness which seemingly speaks only of yesterday. Almost every detail of water-wear can be recognized in them, the same that one sees to-day in the cliffs of such a lake as Superior, or even along the ocean front. The practised eye can at a glance recognize the tool that has been at work. There are no pinnacles, or peaks, or flowing outlines which distinguish the wear of the atmospheric waters; there could not be, as this portion until recently was buried within the lake-waters, and by them protected from outside wear. Above the line of the top terrace, however, or beyond where the lake-waters extended their protecting influence, the scenery at once changes; there are no longer steeply pitching cliffs, but in their place the usual rugged furrows, flying buttresses, and peaky ridges which distinguish the sculpture of the open land-surface.

The history that is taught to us by Lake Bonneville is repeated elsewhere in the United States, and in other parts of the earth's surface. From Oregon southward into what is now the Great Basin, — a region of interior drainage, — and over the area now occupied in part by Pyramid, Humboldt, Walker, and Carson Lakes, stretched in former days Lake Lahontan; and bodies of water of large extent at one time covered perhaps the greater portion of the present Mexican plateau.

CHAPTER V.

SNOW AND GLACIERS.

THE traveller who in Switzerland casts his eye over the wonderful series of mountain heights which there diversify the landscape, and give to it a grandeur which is perhaps to be matched nowhere else on the surface of the earth, sees the upper portions of those mountains bathed in snow, both during the summer and the winter. In the winter-time the snow crawls down nearer to the valleys which echo with the bells of the pasturing cattle, and hangs heavily on the branches of the dark forest which for a distance of several thousand feet climbs up the rugged mountain slopes. It is there augmented by every new snow-fall, and diminishes as the warmth of the sun's rays melts off the material that is furnished to it. In the heart of the summer, except in dark and forbidding gorges or rock-crevices, we rarely see snow below 8,500 or 9,000 feet, because up to this line the sun has proved itself victor in the contest for occupancy; the snow has steadily melted in the path of its coming, and by July or August has pretty generally disappeared. Only above 8,500 to 9,000 feet does it still hang on; thinned off, it yet resists the invasion of the sun, and by its quantity manages to hold possession until refreshed by the next winter's supply.

Snow-Line. — The line or level on any mountain elevation beyond which more snow accumulates in winter than the warmth of summer is able to completely remove, is known as the *line of perpetual snow*, or simply "snow-line." We find such a line on almost every extensive mountain chain, and it is present also on many isolated mountain peaks. Naturally, in regions like the tropics, where the summer heat is greatest and the winter cold least, this line will occupy a high position; in and toward the polar regions, on the other hand, where the conditions are reversed, the line lies low. Hence it is, that while in the Alps the line of perpetual snow is found at about 8,500 feet, in the Equatorial Andes it ascends to 15,000–17,000 feet, and on the coast of Greenland descends to 2,000–3,000 feet. On Mount Etna, in latitude 37° 30′ N., it is found at about 9,500 feet. Nowhere, seemingly, does it descend to the actual sea-level. The quantity of precipitation, which really measures the amount of snow that can accumulate, has much to do with regulating this position. On the Sierra Nevada Mountains of California, which by reason of their nearness to the ocean receive much moisture and a heavy snowfall, the snow-line is found at 11,000 feet; on the eastern Rocky Mountains, on the other hand, to which comparatively little moisture is permitted, owing to the draining of the clouds on the west, the snow-line rises to 14,000 feet.

The Mountain Snows and what becomes of them. — Probably the question has often presented itself to the traveller: What is the thickness of the snow-covering on mountains? And again, Does not this thickness

Plate 24.

THE PHYSIOGNOMY OF A GLACIAL REGION.

The Donkin Glacier, Alberta, Canada (on the right). **L.** Lateral moraine. **M.** Median moraine. **C.** A *couloir*, with forming glacier. **A.** An *arête*, or mountain ridge. **S.** A *col*, or *Juch* (saddle). **N.** Névé, or *firn*. **T.** Talus.

Plate 25.

THE ASPECT OF A GLACIER.

The upper portion of the Rhone Glacier, Switzerland, showing the crevasses, the vertical banding of the ice, and the *Gletscherkorn*, or granular ice (lower right-hand corner).

increase from year to year, or is it nearly constant during its existence? It has been ascertained that on many of the Alpine summits, — the Jungfrau and Piz Bernina, for example, — there is generally a thickness of snow from 200 to 300 feet; and not unlikely many of the Himalayan summits have a still heavier covering. No section of a snow-deposit has ever been measured which much exceeds this development; yet there can be little doubt that in many parts of the Arctic and Antarctic regions the quantity exceeds this by ten or twenty times. On the other hand, it is certain that there are years when this thickness is very materially reduced, to the extent, indeed, of nearly uncovering the entire mountains.

At first sight it would appear that the steadily accumulating snow on a mountain summit, which annually considerably exceeds that which is melted off by the summer heat, must in course of time materially augment the height of that mountain; but we know from a comparison of past and recent measurements that this is not the case. The mountain summits remain approximately of the same elevation, except in so far as they lose height through their own steady disintegration and decay. The process that removes this excess of accumulation is that which is involved in the making of glaciers.

What a Glacier is. — The simplest definition of a glacier is: a more or less united body of ice which has been formed of the upper snows of mountains, and with a steady, usually very slow, movement, slides down the mountain side. By far the greater number of the glaciers of the world, so far as they are known to us, fall under this comprehensive definition. In rarer instances, the snows which make glaciers may of themselves accumulate and become of sufficient thickness without requiring the aid of mountain elevations; such a condition we seem to find both in the Arctic and the Antarctic regions.

For our more intimate conception of this moving river of ice we turn to a study of that wonderland of glaciers, Switzerland. In old and new books, with old and new travellers, there is one particular glacier of the Alps to which, for one cause or another, more attention has been given than to any other. It is known as the Mer de Glace, one of several ice-streams which descend from the northern face of the Mont Blanc, and press their streams as tributaries to the mighty Rhone. It does not essentially differ from any of the hundreds of other glaciers which exist near by, nor is it as massive as many others, ranking only fourth in size of all the glaciers of Switzerland; but it is in a region which is annually visited by thousands of tourists, and this fact has, doubtless, helped to make it of special interest. From a distance this Mer de Glace presents the appearance of a tortuous snow-filled valley, gently pitched in some places, elsewhere breaking down in rapid plunges. The white or gray ice, which the eye clearly follows until it loses itself in the ice-cap, seems like a united body; but, as we approach nearer, we find it broken and torn in pieces by innumerable clefts and fissures (*crevasses*), which traverse it in various directions. What was seemingly a smooth surface is, on nearer acquaintance, a mass of hundreds of pinnacles (*séracs*), so wildly thrown about as to make

Plate 26.

THE ASPECT OF A GLACIER.

Hallett Glacier, Col., showing the irregular surface produced by weathering or melting.

Plate 27.

THE ASPECT OF A GLACIER.

The Mer-de-Glace, Switzerland, with moraine in the foreground. **R** and **P**, scoured rock-surfaces, worn by ice passing in two distinct directions. The horizontal arrows indicate the former reach of the glacier.

travelling over and between them a matter no less difficult than dangerous. Having reached an elevation of about 3,600 feet, we finally stand by the side of the ice itself, and for the first time are in a position properly to appreciate the giant measure of the object that is before us. Across a width of considerably over 2,000 feet, the ice-mass spreads out on either side of us, rising like a steep-sloping mound or hillock, and passing upwards for nearly six miles before it is lost in the perpetual snows of the mountain-top. (Plate 27.)

The Moraine; Glacial Striæ; Erratics.—In front of the ice, and with the ice-nose buried deep within it, is a vast rubble heap of bowlders, pebbles, angular rock-fragments, and sand materials which have been brought along in the course of the moving ice, some of them by actual hard pushing for perhaps miles, others carried on the free surface of the ice, and by it dumped over at its termination. Locally such a heap has long been known as *moraine*, a name which geologists have seen fit to receive into their own technical phraseology. Where we stand, this moraine may be thirty-five or fifty feet in height, elsewhere rising considerably higher, and in other places washed down very nearly to the level of the glacial stream, which cuts through it and issues from the under surface of the ice as a part of its melting waters. We examine many of the bowlders and rock-fragments that lie about us, and note that they differ materially among themselves. Some are rounded, others are angular; the first are worn smooth, the latter are rough, not differing from rock-masses as they present themselves on the untouched mountain face. It takes little study to convince us that the round and smooth pebbles or bowlders have been worn into their present shapes by hard pressure and rubbing — the glacial ice has passed over them or rubbed them hard against their fellows; we find further evidence of this in the grooves and scratches (*striæ*) which furrow their surfaces, and which record their own history. The angular blocks have manifestly not been so troubled, and their travelling has been an easy one. To all these bowlders, as individual objects, whether large or small, geologists have given the name of *erratics* (wanderers); they have travelled with the glacier, and so far as the ice goes and the rock-fragments hold out they go too. (Plate 28, Fig. 1.)

Terminal and Lateral Moraines. — We follow round this end or *terminal* moraine to the sides of the ice-stream, and find that there are similar continuous heaps or lines of rubble which run lengthwise with the glacier, or on its right-hand and left-hand sides. Geologists are in the habit of designating these side lines *lateral moraines*, their position easily distinguishing them from the end or terminal moraine; they extend continuously for nearly the full length of the glacier, generally moved a little way from the absolute margin, but frequently so far spilling over as completely to obliterate the actual border of the ice. The materials of these lateral moraines have been derived from the down-falling *débris* of the mountain side, — most of it, probably, a result of natural rock-decay, the rest gouged out by force-pressure of the moving ice. (Plates 27, 28.)

We have mounted on the top of the ice. We approach cautiously one of the numerous wicked crevasses, and look down its narrow and gloomy space. For 50

Plate 28.

1.

2.

GLACIAL PHENOMENA.

1. A rock-slab smoothed and grooved (striated) through glacial attrition.
2. The front wall of a Greenland glacier, showing the edge of the ice, its stratification, and the end or terminal moraine in front.

or 100 feet, not rarely for 200 or 300 feet, and occasionally for even greater depths, the eye can follow the nearly vertical and adamantine walls of ice, so smooth in places as to reflect the light with the brilliancy of a mirror; elsewhere long icy pendants or icicles, much like the stalactites of limestone caverns, hang closely over the ice-front, descending to depths virtually unknown. The ear possibly catches the sound of running water, for under-ice streams are plentiful; the waters from the melting ice all gain the bottom, and there they course about until they unite in one or more main streams. In the heated hours of the day the surface, where not molested by ragged crevasses, is musical with the song of gurgling rills and rivulets, which here and there cascade into the vertical clefts, or plunge into great holes (*moulins*) which they themselves have in part excavated. In the hours of night the music of the glacier usually ceases, for then the melting has stopped, and there is but little flow of water. A rock perchance tumbles off its purchase, or the ice creaks and groans under the straining pressure to which it is subjected; but the ice-river is on the whole silent, to be again awakened into active life with the return of the day's heat. Its motion has not stopped, however, although it has slackened; winter and summer, night and day, the mighty stream continues pressing forward, but its movement is less rapid in the hours and periods of cold than in those of heat.

As we laboriously climb over the surface of the ice, we note that where the glacier is more nearly horizontal in position, or occupies a flat bed, the ice shows a tendency toward unity; the crevasses have largely disappeared, or at least have been so closed over as hardly to be visible. On the other hand, where the glacier breaks from a nearly horizontal bed to one that is steeply pitched, the surface becomes raggedly crevassed and fractured. We conclude, therefore, that the ice has been torn apart by travelling over an uneven and irregular surface, just as would also be the case if the travelling medium were, in place of ice, a somewhat liquefied mass of tar or treacle. On the level parts of the course the rents or tears have again been united by being pressed together, and the glacier presents a more or less solid body. Where it passes around great curves the ice also breaks and fractures, once more to be built together where the stream regains its straight course.

The Forming Basin of the Ice (Névé or Firn). — We have now travelled five or six miles over the torn ice-sheet, have seen it where its slope is so nearly flat that its departure from the horizontal line can hardly be detected by the eye, and have climbed its face where it plunges cataract-like at an angle of fifteen to twenty degrees. The lower glassy ice has been left behind us, and we have under our feet a coarse, granular mass made up of rounded parts of about the size of a walnut or a hazel-nut (*Gletscherkorn*); still farther up, these disappear, to be replaced by a fine grain; and finally we arrive at a point, perhaps 9,000 feet up on the mountain, where the granular ice merges into the granular snow (*firn* or *névé*) out of which it has been constructed. This is nearly the full aspect of the glacier, and it represents almost all that belongs to any other glacier. (Plates 24, 25, 26.)

Our brief study has now prepared us for the question: How is the glacier formed? The process is a simple one, and one that is practised to an extent by every street-boy who lives in a region where snow falls. In making so simple an object as an ice-ball, we do very much what nature does to make a glacier. In the first place, we compact the snow with our hands, and secondly warm it by contact, and then allow the water that has formed from the partial melting to freeze the whole solid. This is the ice-ball. This process is in a general way repeated in the making of a glacier. In most regions of glaciation the snow that forms the glacier accumulates in an extensive mountain hollow or basin, where it heaps up layer upon layer with every fresh snowfall. Commensurately with this upward growth, the lower layers become more and more compressed, and into them descends a certain quantity of "liquid" moisture which has been liberated through the energy of the sun's rays. With the return of the cold evening and night, the whole freezes solid, and we have the first ice of the forming glacier, — a granular mass, of about the texture of coarse sugar, and built up in distinct layers (strata), corresponding more or less closely with the different beds of snow. This is the *névé* or *firn-ice*, built up in the *névé* or *firn-basin* from which the glacier issues, and which usually occupies a position considerably above that of the snow-line. When the ice has become sufficiently massive and crowded it is gradually pushed out of this basin, and then begins the long and tedious journey down the mountain side, usually in a formed depression or valley, which is the glacial movement or flow. (Plate 29, Fig. 1.)

Compound Glaciers; Medial Moraines. — Under this name are properly designated those ice-sheets which have been formed through a coalescence of two or more glaciers flowing in independent valleys of their own; in such cases the united parts usually retain their own individual positions in the main stream, flowing together, but not in a heterogeneously mixed-up mass. The lateral moraines of contiguous glaciers become, however, merged, and they then constitute a *medial moraine;* as many as ten or fifteen such medial moraines are found in some glaciers, and indicate a union of as many streams. (Plate 29, Fig. 1; Plate 24.)

Plate 29.

1.

2.

THE PHYSIOGNOMY OF GLACIERS.

1. The Aletsch Glacier, Switzerland, showing its composite structure in the number of medial moraines.
2. Side view of the Fan Glacier, North Greenland; it debouches upon a flat meadow-plain. The stratification of the the ice is well marked.

Plate 30.

1.

2.

THE ASPECT OF A GLACIATED REGION.

1. The summit of the Shawangunk Mountains ("Sam's Point"), N.Y., smoothed and rounded by the glacial ice of the Glacial Period.
2. A glaciated expanse of rock near Halifax, N.S., showing parallel glacial striæ.

CHAPTER VI.

THE WORK OF GLACIERS.

The Flow of Glaciers.—It is to-day well established that the motion or flow of glaciers is principally, if not almost entirely, conditioned by the force of gravity; the ice-sheet, squeezed from behind, tends steadily downward, just as a river of any viscous substance would do. It yields to this flow largely because ice is in a measure plastic, and permits itself to be moulded and drawn over the face of intervening obstacles; hence it is that the glacier overcomes, even on most moderate slopes, the enormous resistance which friction with the floor of the valley imposes upon it. In its own general flow, different parts of the same ice-stream move with different velocities; the top layers move more freely than the lower ones, which are hard-pressed against the bottom, and the central portions more rapidly than the lateral ones, which are retarded by scraping along the mountain sides. This irregular movement causes "shearing" of the ice, layers being tossed up, over, and above one another, accompanied perhaps by an endless number of breakages. A large portion of both the longitudinal and the transverse fissures is the result of unequal strain brought about in this uneven flow; and were it not for the property that ice possesses of repairing itself,—*regelation*, when smooth surfaces are brought together at about the temperature of melting, — the glacier would be even much more rent asunder than it really is. When rounding a sharp curve the glacier tears on the outer side and is compacted on the inner, and this process may reverse itself a number of times on opposite sides. In a general way the flow conforms largely to the laws which govern the flow of liquids and half-solids, the viscosity of the ice being an alternative to the freely moving globules or particles of water.

The Rate of Glacial Movement. — The rate of flow depends upon a number of special conditions, the most potent of which are: the bed, the mass of the ice, and the temperature of the atmosphere. Other conditions being equal, the flow is most rapid on a steep slope, when the volume of the ice is greatest, and when the temperature of the air is highest. It is more rapid in summer than in winter, in the warm hours of the day than in the cold of night. Again, the flow is faster in the top ice of the glacier than in the bottom ice — hence the overhanging termination which is often found — and in the centre than on the sides; to the latter circumstance is due the frequently curved or fan-shaped front of the ice-sheet. The stream compresses itself in narrow courses of its journey, and spreads laterally in opening plains and valleys. In the greater number of the Alpine glaciers the rate of the fastest flow hardly exceeds two to three feet per day, and very frequently it does not even reach half of this amount. In hard winters the flow at times almost ceases; on the other hand, a few instances are recorded, as in the case of the Vernagt Glacier, in 1845, where the advance of the ice covered between thirty and forty feet in the period of twenty-four hours. Nearly all the glaciers of the world that have been so far studied, whether of the Caucasus, the Himalaya, the Andes, or of Scandanavia, are slowly moving ones. In or toward the Arctic regions there is a tendency to accelerated motion; and if we are to credit fully the observations that have been made in some of the largest glaciers of Greenland (Jakobshaven), there must be an advance in those parts of sixty to seventy feet per day; at the same time it is certain that the greater number of the Greenland glaciers, whether large or small, have only the motion of the glaciers of Switzerland.

Glacial Scour and Polish; Roches Moutonnées. — It can hardly he conceived that so massive a body of ice as is represented in a glacier could slide over its bed without putting to some extent its impress upon it. It rubs over the rocks, grooves and scratches them with the small pebbles that lie frozen in the under surface of the ice, and it probably even does a certain amount of direct excavation or "scraping out." All this is known as the work of the glacier, and its measure is a fair index of the size of the ice-sheet that brought it about. The greater number of the grooves or striæ naturally follow in the line of movement of the ice-flow, and are therefore more or less parallel with one another. (Plate 30.) Those of the ordinary kind, perhaps hundreds of feet in length without a break, have a width of barely more than an eighth or quarter of an inch, looking like pencil furrows; elsewhere they expand into grooves of from one to three feet in width, or even more, or make distinct flutings in the rock.

Through shearing of the ice, or through a cross-flow, these striæ may be made to cross one another, and thereby produce a puzzling sculpturing of the rock surface. It is not only the bed-rock that is striated in this manner, but the feature belongs to the overlying bowlders as well; hence we have a distinctive mark or character impressed upon the true "glacial bowlder," by which it can in most cases be easily recognized.

In association with the striating and rubbing of rock-masses, there is not infrequently a pronounced "polishing," the surface being ground and rubbed so smooth as to show an almost mirror-like texture. Even the hardest rocks may be rubbed perfectly smooth; at times they are left with an even and nearly horizontal surface; at other times they are ground into a series of hummocky swellings, or mammillations, the *roches moutonnées* of the glaciated landscape. (Plates 30, 31.) By many geologists the very troughs or valleys which the glaciers themselves occupy are assumed to have been worn by a slow but continuous ice-action, extending certainly over thousands of years; and even the great lakes which lie by or near these valleys, like many of the lakes of Switzerland, are by some attributed in their formation to glacial scour. And there is really much to support this view, even if it cannot be said to be as yet definitively proved; for it is certain that the form of the glacial valley is usually quite different from the valley worn by simple water-action, — being flatter and with a broader base, — and that a surprisingly large number of lakes are to-day found in regions of actual glaciation, or of glaciation which culminated in a geologically recent period. Some geologists have attempted to deny to the glacier all excavating power, asserting that no glacier of to-day can be seen working in this way, while many even of the larger ice-streams pass over loose earth and grassy patches without materially disturbing either the one or the other. There is no questioning this condition; but it is an exceptional one, and the fact that the ice smooths off and rounds over the rock-surfaces upon which it passes, is a clear indication that it must do some excavating, however small or insignificant. Again, however unimportant this work may appear, by multiplying it through a long number of active years of work, an astonishingly large result may be reached. Thus, if we assume that the ice excavates only the one-twelfth of an inch per day, which ordinary observation could not detect, by the amount of excavation in the short period of one hundred years would be a hollow two hundred and fifty feet in depth, and in a thousand years, twenty-five hundred feet, far greater than the depth of the deepest of the Alpine lakes. This would easily make it possible that the largest of the rock-basins have been made through glacial scour, the work of glaciers no longer existent, or of such as are to-day merely the remains of former greatness.

Drift. — Under this name geologists usually class the various forms of deported material, the bowlders, pebbles, and sands, which lie in the path of the moving ice, or mark the passage of ice that formerly existed in a region and has since disappeared (ancient glacier). It therefore comprises the erratics which have already been described. There are ordinarily two forms of drift recognized, a *high-level* and a *low-level drift*, each of which marks relative positions or sites occupied by the transported material. High up on the mountain slopes, in regions of past glaciation, we find the erratics or bowlders of high-level drift, while the valleys are perhaps deeply buried beneath the materials of the low-level drift, — materials which the glacier pushed along on its bed as the *ground moraine* (or "till"). To this latter class belong the pyramidal or lenticular mound-like hills of sand and cobbles, so distinctive of the landscape of many glaciated regions, and known as "drumlins," "kames," and "eskers," some of which lie longitudinally in the course of movement of the glacier, others transversely to it. The precise method of their formation has not yet been determined; although it seems likely that some of them, at least, were an underwash into cavities or hollows of the ice.

The Retreat of Glaciers. — Probably every region of glaciation has periods of most active movement, when the ice-sheets are more steady in their advance than at other times, and reach a prolonged maximum extension. Such periods of advance may be protracted over a goodly number of years, and are then usually followed by periods of retreat, not necessarily of equal length. In such periods of abatement the intensity of the lower temperature has melted off more ice than was furnished to the glacier from above. Most of the Alpine glaciers, up to within the last few years, had for a decade or more been on the retreat, and some of them very rapidly so. Necessarily, when this recession takes place, the ice separates (recedes) from its terminal

Plate 31.

1.

2.

THE WORK OF GLACIERS.

1. A rock-surface planed by glacial passage (indicated by the arrows), with rock-islet (*nunatak*) around which the ice moved (outer Duck Islands, off Greenland).
2. The roches-moutonnées of the Grimsel, Switzerland — the rounded and polished rock-surfaces showing glacial scour.

Plate 32.

1.

2.

THE WORK OF GLACIERS.

1. The hummock "short hills" of a portion of the great moraine of Pennsylvania.
2. Section of a moraine near Whitewater, Wisconsin.

moraine, and leaves it standing in marked isolation, — a landmark of former occupancy by the ice, now, perhaps, removed from it by a full half-mile or more. The glacier had in the meantime constructed for itself a new moraine, defining as before the termination of the ice-sheet. In valleys of considerable recession we frequently meet with as many as six or eight transverse moraines placed at irregular intervals back of one another, each one marking a temporary pause in the almost continuous drawing back of the ice.

Distribution and Dimensions of Glaciers. — The regions of most extensive glaciation at the present time are to be found in the Arctic and Artarctic zones; Greenland is buried beneath an ice-cap which radiates off hundreds or thousands of glaciers into the water-areas by which it is surrounded, and much the same condition appears to prevail over what is commonly designated the Antarctic continent. Following these polar tracts in the extent of their glaciation, are the Himalaya Mountains, the Alaska region (Muir Glacier), Alps, Caucasus, Scandinavian Alps, Andes, and the North American Cordillera (Selkirk Mountains), etc. Some of the extinct or semi-extinct volcanic cones of the United States (Tacoma, Shasta, etc.) bear on their summits glaciers, although of not very great extent. Among oceanic islands, — barring those of the Antarctic tract, — Spitzbergen (Dove Glacier) and New Zealand (Great Tasman Glacier) have probably the largest glaciers. The largest authenticated glacier of to-day is the Humboldt Glacier, which discharges into Smith Sound, off the north-west coast of Greenland, with a frontage said to be sixty miles in length. The northern shore of Melville Bay is seemingly a continuous glacier for at least thirty miles. The Biafo Glacier of the Himalayas measures about forty miles in length, the Muir Glacier of Alaska probably thirty miles, and the Aletsch, the largest of the Alpine glaciers, about thirteen miles (inclusive of its upper snow-field). In some of these glaciers the ice is not less than 300 to 400 feet thick; indeed, Agassiz had assumed that the thickness of the Aar Glacier of Switzerland was at least 800 feet. It is not impossible that some of the Antarctic glaciers measure 2,000 to 3,000 feet in thickness, or even more; but such a development of ice has not yet been proved to exist.

Evidences of Past Glaciation; Great Ice Age. — All over the north of Europe, extending southward to about the 49th parallel of latitude, we have in the scattered drift, in the polished and striated rock-surfaces, evidences of former possession by the ice where ice no longer remains. A large part of the North German plain, of Central Russia, etc., with parts of Great Britain, speak plainly the evidence of past glaciation; and the character of many of the travelled bowlders shows them to have come from the north, from the Scandinavian Peninsula. The lowland plains of Switzerland, the eastern heart of France, the north of Italy, speak equally of a glaciation which was far more extensive than the glaciation that to-day characterizes the Alps; but in this southern glaciation, which appears to have been contemporaneous with that of the north, we see only an expansion of the existing glaciers of the Alpine system; some of them extended thirty, forty, or even fifty miles beyond their present limits; indeed, the Rhone glacier, of which we have but a fragment remaining, appears to have travelled quite to the outskirts of Lyons, in France, a distance of full two hundred miles. During this period of excessive Alpine glaciation, when possibly the mountains were raised thousands of feet above their present summits (and in this way accumulated the necessary snows to make these huge ice-sheets), the lowland of Switzerland was covered by ice, thousands of feet in thickness, which filled in the valleys, and distributed its bowlders high up on the distant mountain flanks.

Even more extensive are the traces of similar, and not improbably simultaneous, glaciation on the North American continent. The area of drift, of bowlders, sand, striated and polished rock-surfaces, occupies most of British North America east of the Cordilleras, and descends into the United States to the 40th and 39th parallels of latitude. Over the whole of New England, nearly to the tops of the highest mountain summits, across the State of New York and into northern New Jersey, Pennsylvania, and central Ohio, and westward beyond the Mississippi River in Minnesota, are distributed in various forms the traces of this wonderful visitation of ice, the exact nature of which is not yet fully understood. By some, this ice has been looked upon as being a united and single sheet; by others, and probably with more reason, as a union of more or less confluent ice-sheets or distant glaciers, to all of which, within the domain of the United States, a southern or southerly direction had been given. The striæ point south-eastward, southward, and south-westward, radiating out in fan form from the region of the

Canadian boundary. Further to the north, in Canada, Labrador, the Northwest Provinces, and Newfoundland, the striations point poleward in the main. Seemingly, therefore, a starting-point for both north and south movements must have been somewhere about the tract which is commonly designated the Height of Land. Possibly in this great glacial period, or *Ice Age* as it is commonly designated, the mountains stood much higher than they do to-day, and not improbably a considerable portion of the continent itself stood higher.

The Great Terminal Moraine. — Geologists have designated under this name a vast rampart-like series of undulations, composed of pebbles, sand, and bowlders, which extends with almost full continuity from the Atlantic border of the United States, — through Cape Cod, the Vineyard Islands, Long Island, etc., — westward to the Mississippi River, and with a north-westward deflection into Canada, and seemingly marks the southern limit of flow of the continental ice. This moraine, assumed to be the correspondent of the terminal moraines of ordinary glaciers, rises over mountain ridges, and descends across valleys, here and there broken down to water-level, and elsewhere washed away by the streams that break through it, and that convey still farther southward the *débris* as part of their sediment. In places this moraine rises from eighty to one hundred and fifty feet or more, and its peculiar "short hills" impress a distinct individuality upon the landscape of which they form a part. Numerous small lakes, ponds, and tarns occupy its hollows, or "kettle-holes," as "moraine lakes." It has now been pretty well established that this so-called terminal moraine has, at least in part, a double construction, and represents a partial retreat and re-advance of the ice; but there is no evidence that two distinct ice ages were involved in its making. Several of the large northern lakes (Michigan, Erie, Ontario) are outlined by morainic "lobes," and it is certain that the basins of all of these were occupied by glacial ice; but to what extent the ice was instrumental in shaping these basins, as well as the basins of the almost endless number of lakes in Maine, New York, Minnesota, etc., which are found in the glaciated tract, remains to be determined. (Plate 32.)

Cause of the Great Ice Age. — Nothing positive is known regarding the causes which brought about this vast accumulation of ice. By some physicists the occurrence is attributed to purely astronomical conditions, changes in the relative position (as to nearness or distance) of the earth to the sun; and by others to a different distribution of the land and water-areas of the globe than that which is to be found at the present time. The subject is seemingly too remote from solution to require discussion in this place. It has also not yet been conclusively demonstrated whether distinct glacial periods successively repeated themselves in past geological history or not; nor do we know, in precise enumeration of years, what length of time may have elapsed since the closing of the period which is commonly designated the Ice Age. Man was certainly an inhabitant of the planet during some of its existence, and probably long antedated it. By some geologists the disappearance of the ice is assumed to have been no longer ago than 10,000 years; by others it is placed as far back as 75,000 or even 100,000 years. One fact is clearly established: many of the surface features of the regions that were formerly occupied by the ice — the river-gorges, valleys, etc. — have been carved out since its disappearance.

The Niagara Falls and gorge of the Niagara River have frequently been taken as the measure of time by which to interpret the period that has elapsed since the disappearance of the ice. But the length of time involved in the cutting of the gorge is in itself doubtful, and has been variously put by geologists as between 7,500 and 35,000 years, the probability inclining in favor of the longer period. The uncertainties that connect themselves with calculations of this kind are too numerous to permit much weight to be attached to a general result.

Plate 64.

GLACIATED REGION OF THE NORTH-EASTERN UNITED STATES AND SOUTHERN CANADA.

CHAPTER VII.

THE WORK OF UNDERGROUND WATERS.

Mineral Waters. — The fact that all rock is more or less porous, and admits of the passage into it of a certain quantity of water, is sufficient proof that every portion of the earth's surface that receives rain is to some extent invaded by underground water. This condition is directly brought to our notice in the numerous streams and springs that issue at the surface. Some of these do not differ essentially from the streams that flow directly over the surface; others have become impregnated with the earthy materials of the interior, and have thereby become converted into "mineral springs." As such we recognize a number of distinct types, depending upon the special mineral substances which the waters hold in solution. For example, we have saline or salt springs, which contain the chloride of sodium, or ordinary salt, in solution; chalybeate springs, or those which are largely impregnated with iron; bitter springs, which contain the salts of magnesia (Epsom waters); lime springs (like those of Carlsbad), which hold the carbonate of lime; alum springs, soda springs, etc. The quantity of foreign material thus held in solution differs greatly, and is necessarily dependent upon the qualitative structure of the rock-masses, upon the length of course of the underground stream, and also largely upon the temperature of the acting water — the higher the temperature, the greater its solvent power.

The Formation of Earth Voids; Caves. — The absorption of the solid materials of the crust by underground waters, and their carriage to the surface, mean, necessarily, the creation of internal voids; these, small at the start, may develop into great expanses, and we then have the formation of caves and rifts. Especially is this the case in limestone regions, and to a less extent in regions of gypsum deposits, where both the carbonate and the sulphate of lime undergo rapid and easy solution. All the really great caves of the world are in limestone rocks, whether they are of marine or of fresh-water origin; i.e., whether carved out by the oceanic waters, or worn out by the travel of underground streams. Some notion of the prodigious quantity of material that is brought up from the interior through the solvent action of water may be gathered from the fact that the brine-spring of Neusalzwerk, in Westphalia, discharges annually a quantity of common salt that is the equivalent of a cube of seventy-two feet dimensions, and in addition a quantity of limestone that would make a cube of twenty-four feet. One of the warm springs of Leuk, Switzerland, whose temperature is 144° F., has been estimated to discharge annually nearly 9,000,000 lbs. of gypsum, or the equivalent of 60,000 cubic feet. The potency of this kind of work cannot be overestimated, and it leads to the easy comprehension of the manner in which a cave is formed.

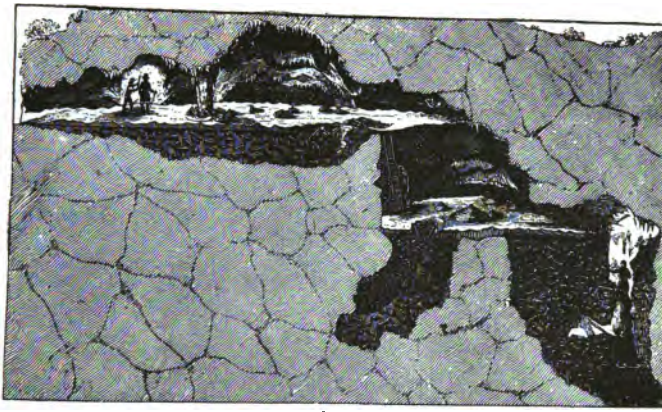
Among the largest caves of the world are the Adelsberg and Aggtelek, in Austria-Hungary, Weir's and Luray caves in Virginia, the Howe cave in New York,

Plate 22.

THE WORK OF UNDERGROUND WATERS.

The Hermannshöhle, in the Harz Mountains, Germany, showing stalactites and stalagmites.

Plate 23.



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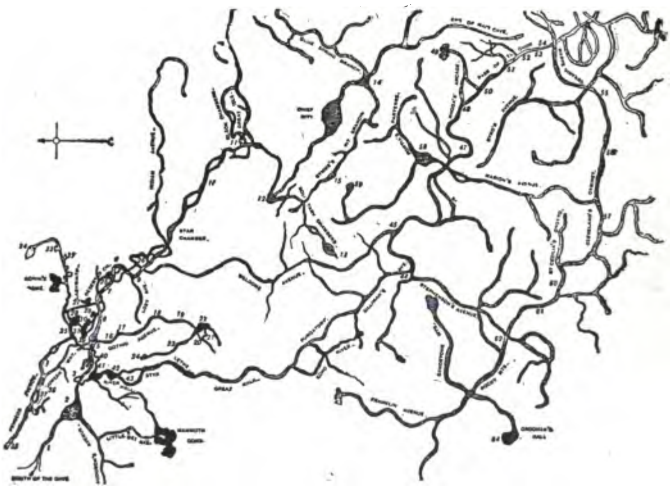

2.

THE WORK OF UNDERGROUND WATERS.

1. Generalized section-plan of a cave: The bone-cave of Gailenreuth, Bavaria, showing the relations of the different chambers.

2. Plan of Mammoth Cave, showing the courses of the different passages (after H. C. Hovey).

and the Mammoth cave of Kentucky; the last, lying in the course of the Green River, is, in the direct measurements of its passages, probably the longest of all known caves, measuring eleven miles or more. The height of many of the chambers exceeds 70–80 feet, and exceptionably it reaches 200 or even 250 feet (Mammoth Dome), the connecting passages being usually very low. (Plate 23, Fig. 2.)

Cave-Rifts and Bone-Caves. — These structures differ from true caves mainly in their contracted areas; instead of expanding out into roomy chambers, they are more generally of a cleft or fissure type, abrupt and tortuous. Doubtless, further excavation by solvent water would in course of time convert many of them into true caves. In some cave-interiors and cave-rifts there have been accumulated extensive deposits of animal remains, mainly the skeletal parts of extinct and living quadrupeds, such as the cave-bear, cave-lion, rhinoceros, mammoth, mastodon, hyena, buffalo, sabre-tooth tiger, giant sloth, etc. Some of these may still be living in the region where the special cave is found; elsewhere they have been removed by a broad migration. Among the better known of these *bone-caves* are those of Kirkdale, Kent's Hole, and Wookey, in England; Gailenreuth in Germany; and Carlisle and Port Kennedy, in the State of Pennsylvania. How these masses of remains collected in the cave-interiors is still a question of probability, and perhaps no explanation is suited to all the different cases. In some instances it appears certain that the animals to whom the parts belonged tumbled in accidentally through a chance surface opening; elsewhere, some of the forms, like the hyenas, may have been actual cave-inhabitants, with predatory habits that brought their food-supply within the boundaries of their habitations; and finally, in many, and perhaps in most instances, the accumulations have followed in the course of inundating floods. It is in these bone-cave deposits that there have been found some of the most ancient remains of man, — the Neanderthal skull, from the Neanderthal Cave, near Düsseldorf, Germany, the "fossil man" from the cave of Mentone and the caves of Brazil, — and with them some of his most ancient belongings (chipped implements, etc.). None of the bone-caves appear to be of really great antiquity, although their existence unquestionably covers many thousands of years. (Plate 23, Fig. 1.)

Natural Bridges. — Closely connected with cave-formation are the "natural bridges" which span chasms in the limestone rock. Many of these are unquestionably only parts of cave-roofs, which have remained standing after the caves themselves have disappeared through natural destruction. Such appears to be the famous Natural Bridge of Virginia, with a height of 215 feet, a span of 60 feet, and a thickness of rock of 40 feet.

Stalactites and Stalagmites; Ice-Caves. — Under these names we understand the peculiar and frequently fantastic deposits of lime that have been shed by the percolating waters of caves. They dissolve a certain quantity of the lime-carbonate in passing through the rock, and again deposit the same when their solvent power has been measurably reduced. In this way are formed the large pendants (*stalactites*) which hang from the roof, and the columnar buttresses (*stalagmites*)

Plate 33.

1.

2.

THE WORK OF HEATED WATERS.

1. The cone of Giant Geyser, Yellowstone National Park.
2. A cone of a hot-spring in the Yellowstone region.

which rise from the floor. The various forms of "organ-pipes" and "curtains" are merely modifications of the ordinary stalactite structure, just as the "floor-crust" is merely a variety of the stalagmite. (Plate 22.) The vast deposits of "Mexican onyx," so-called, are stalagmitic infiltrations between the layers of regularly stratified marine strata. In this connection should be mentioned a class of caves which differ from the ordinary lime-crusted ones in the fact that the interior deposits, whether as floor-crusts, stalactites, or stalagmites, are of ice-formation instead of carbonate of lime. Such ice-caves are of somewhat frequent occurrence in the mountains of Europe,—in the Alps, Jura, Carpathians, Urals; and some of them are 300 to 400 feet in length, with a height of chamber of 100 feet or more. The largest of these caves are those of Kolowrat, near Salzburg, and Dobschau, in northern Hungary. The manner of ice-formation is not precisely known: in some it seems to be an accumulated winter deposit; but in others it would appear as though the freezing took place in early summer, the slow percolation of melted waters from the outside finding in the interior a sufficiently low temperature to bring them to a condition of freezing.

Hot Springs and Geysers. — Reference has already been made to the heating up of waters when they gain the deep interior of the earth; when they rise to the surface with a marked accession of temperature they constitute the well-known "hot springs." The thermal springs of Bath, England, have a temperature of 120° F., which, in accordance with the law of increase of 1° F. for about every 60 feet of descent, would indicate a rise from a depth of about 4,000 feet; the waters of Chaude-Aigues, in France, have a temperature of 178°, which indicates a depth of origin of at least 7,000 feet; and those of the rivulet of Trincheras, in Venezuela, had in 1823 a temperature of 206°. The forms of hot springs known as *geysers* differ mainly from the ordinary type in having their outflow accompanied by intermittent or paroxysmal explosions of boiling water and steam. In its general structure the geyser consists of three or more essentially different parts: 1, the underground irregular course of the spring-waters; 2, a vertical conduit of varying depth through which the waters pass before gaining the surface; and 3, a mound or cone (the "geyser cone"), with a top-basin, which has been built up of the siliceous material which the stream has itself deposited at its point of exit from the earth. The vertical conduit just referred to is a central passage or shaft which traverses this cone.

The explosions which characterize geyser action are brought about as the result of two conditions: 1, resistance to the escape of imprisoned steam by the pressure of the column of water contained in the conduit; 2, release of this pressure through a change in the equilibrium between the acting and resisting forces. The greatest development of geyser action is to be found in Iceland, New Zealand, and the Yellowstone National Park, more especially in the last-named region. Among the better-known geysers of this tract are the "Giant," whose jet is sometimes thrown to a height of 200 feet, and whose cone measures but ten feet in height; the "Beehive," with a jet of 200 feet, and a cone of three feet; the "Liberty Cap," whose

Plate 34.

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2.

THE WORK OF HEATED WATERS.

1. Crow's Nest Geyser, New Zealand, in eruption.
2. The cone and terraces of Castle Geyser, Yellowstone National Park.

Plate 35.

THE WORK OF HEATED WATERS.

The White Terrace of Rotomahana, New Zealand, destroyed by the eruption of Tarawera, in June, 1886.

cone measures 50 feet in elevation; and the "Grand Geyser," which plays from a mound measuring 50 feet in diameter, and only one foot in height. (Plates 33, 34.)

In immediate association with geyser action must be classed the large deposits of siliceous and calcareous *sinter* which are precipitated by the superheated and highly charged waters of the geyser region, and in some instances form most picturesque and noble features in the landscape. The travertine terraces of Gardiner's River, in the Yellowstone region, are an example of this kind; and still more noted were the famous "Pink" and "White Terraces" of Rotomahana, New Zealand, — destroyed by the eruption of Tarawera in June, 1886, — which in beauty and scale of development far surpassed all other similar structures, and were by many classed among the wonders of the world. (Plate 35.)

CHAPTER VIII.

THE RELATIONS OF THE SEA TO THE LAND; OR WHAT THE SEA DOES AND WHAT IT UNDOES.

Configuration of the Oceanic Trough. — There are many who even to-day believe that the moment you leave the continental borders you almost immediately step out over the great deep sea — the "unfathomable" ocean. They may have heard of ships grounding miles away from shore, may have seen the masts of the vessels that are held fast; but, beside the old notion of immediate profundity, these direct evidences of shallowness carry little weight. As an actual fact, the border strip of the greater part of the ocean is a very moderately shelving plane, dropping so gradually that in sections of a mile the fall could hardly be detected by the eye. Off the east coast of much of the United States, — off New Jersey, for example, — the seaward slope for a length of some seventy miles or more is on an average not more than seven or eight feet to the mile; which means that at a distance of fifty miles from the land the depth of water would not be sufficient to submerge the steeples of one of half a dozen European cathedrals, were these buildings carried out to sea to the distance mentioned. A half-mile away, a man could in places wade about with his head out of water. Off some parts of the Irish coast the shallows extend still farther seaward, dropping on an average six feet per mile for 200 miles. In a general way it may be said that this oceanic shallow, or "continental shelf" as it is most commonly called, extends out from fifty to seventy-five miles, beyond which the descent of the sea-bed is rapidly more abrupt. In a horizontal distance of ten miles it may fall 9,000 or 10,000 feet, but even this is not that stupendous plunge which, in many minds, is associated with the oceanic basins; in fact, there is hardly a slope in any part of the oceanic trough — except perhaps among certain coral islands, or among the islands of a recently broken-in land-mass (as is represented by the Grecian Archipelago) — which could not be readily traversed by a horse and wagon.

The Origin of the Oceanic Trough. — Concerning the origin of the continental shelf, or what this continental shelf really signifies, there is little to be said. By some it is assumed to have been built up from the oceanic depths through the accumulation of sediment derived from the destruction of the continents; by others it is conceived to be part of the continent itself, at the present time submerged. This latter interpretation is probably more nearly the correct one. As a question in physics, there is not one more interesting than that which relates to the origin or construction of the oceanic basins themselves. The questions: How were they formed, when were they formed, and what will become of them? puzzled geographers and geologists more than a half-century ago, and they still continue to puzzle. Perhaps the nearest approach to a true answer to the question of origination is that which assumes the oceanic troughs to be parts of a series of giant folds — of which the continents are another part — made when the earth first contracted as a cooling mass; and that the present profound depths have been brought about by successive breakages or subsidences of the ocean-floor. At any rate, it is nearly certain that we are correct in interpreting the oceanic basins as areas of weakness in the crust, a weakness which was initial with the first making, and has continued ever since. The large number of volcanic disturbances which take place in various parts of the oceanic abyss, around and in the numerous islands that rise out of it and along the continental border-line, and the almost innumerable earthquake tremors and dislocations, are facts that go far to sustain this view, even if they do not absolutely prove it. Further, there is reason to believe that much of the existing basins, Atlantic and Pacific, was made (geologically speaking) in comparatively recent times, although some parts of them are doubtless very ancient.

Permanency or Non-Permanency of Continents and Oceans. — A question of much interest that has from time to time engaged the attention of geologists is that which relates to the permanency or non-permanency of the oceanic troughs. When in our rambles across country we come upon giant rock-masses that protrude their heads through a crumbling soil or the smiling carpet of grass and flowers, we know that in those rocks we have the evidences of former possession by the sea. There are the heavy beds of limestone, of shale, of sandstone; there are the impressions of the life that tenanted the seas — shells, corals, crinoids, etc. Here, again, is this vast deposit of pudding-stone or shingle, the veritable beach-line of an ancient sea; and there the marks of the ocean's ripples. We may travel from one end of the continent to the other, or to the farther ends of any continent, and from the sea-level to very nearly the highest points of all mountains, and we shall almost everywhere find conclusive evidence that formerly the sea, at various periods, occupied the region over which we are travelling. East of the Alleghany Mountains, west of the Alleghany Mountains; east of the Rocky Mountains, west of the Rocky Mountains; and in the great central basin, — it is all one history, a history that repeats itself in England, France, Russia, China, Australia, everywhere.

Of one fact we have thus made certain: the continents, at least, have not been permanent. They have been covered by the water of the ocean once, twice, several times, and to varying depths of from 1,000 to 5,000 feet, and not improbably of even 8,000 to 10,000 feet. Whether or not beneath this deep covering of water they were then marked off from still deeper oceanic basins, and in a way constituted "submerged" continents, or continents in preparation, cannot now be told, although many have argued in favor of such a supposition.

Disruption of Continental Masses. — The remaining part of the inquiry rests with the sea itself. Have its greatest depths always been depths since they were first formed, or has the ocean-floor been from time to time elevated high and dry, and again as often depressed? To this question no positive answer can be given, but probability favors the view that the greater depths have been steadily or progressively getting deeper. With this understanding there would be a certain amount of permanency established for the oceanic basins; but this supposition in no way asserts that large continental areas may not have dropped or subsided within the troughs that to-day belong to the sea. The North and South Atlantic basins may well have been in existence when an east-and-west or north-east-and-south-west land connection still united the America of the New World with Europe and Africa of the Old. There are many reasons for believing that this was actually the case. Again, it is certain that a large Arctic continent has been shivered up and lost beneath the waters of what are at present a part of the Atlantic and the Arctic basins. The remnants of this continent are still to be seen in the lands of Greenland, Spitzbergen, Nova Zembla, and in the disjointed tracts that lie north of the American continent. In the Antarctic realm even more disruption appears to have taken place.

Configuration of the Atlantic Basin. — The existing conformation of the Atlantic trough shows it to be a double basin, with an easterly and a westerly half, between which runs a dividing ridge or backbone, whose top parts are still submerged some 8,000 or 10,000 feet beneath the surface of the waters. This longitudinal ridge is commonly known under the two names of the "Challenger" (for the southern half) and "Dolphin" (for the northern half) ridges. In the deeper basins that lie on either side of this ridge a depth of water is frequently found of 15,000 to 17,000 feet, increasing in places or spots to 20,000 and even 25,000 feet; the greatest recorded depth of the Atlantic is 27,366 feet, found some sixty miles from the island of St. Thomas. What the depressed ridge of the middle Atlantic means, has yet to be determined; some have argued with much plausibility that it represents a sunken mountain chain, and with it, perhaps, a sunken continent. The fact that a number of volcanic islands of the Atlantic are perched upon this ridge as steeply rising volcanoes, just as we find the great volcanic peaks of South America implanted upon the mighty Andean ridge, carries weight in this connection; but probably it does not quite prove the case. The Pacific Ocean has no such defined separating backbone, although it has a number of very distinct submerged ridges of minor extent, usually with a north-west and south-east trend, which carry many of the almost innumerable volcanic and coral islands and islets that are scattered about. The greatest known depth is 29,200 feet, found in latitude 24° S., very nearly due south of the Friendly Islands. This is almost exactly the equivalent of the highest known elevation of the land-surface, Mount Everest in the Himalayas (29,002 feet), but this correspondence has no special significance. The average depth of all the oceans is probably in the neighborhood of 12,000 feet.

Inconstancy of the Ocean-Level; Oceanic Transgressions and Recessions.—It is customary to look upon the surface of the sea as having a very nearly uniform level, known as the "level of the sea," from which our ordinary calculations of land-elevation and sea-depression are made. That this level cannot be uniform for all parts of the earth becomes evident the moment we consider what must necessarily result from the attracting power of gravity. All bodies attract one another in degrees proportional to their masses; hence, the sea is drawn upon all sides by the continental buttresses that surround it, and proportionally to the sizes of those continents. The greater in bulk the continent, the greater will be its attracting power; and where specially large mountain masses are grouped about certain parts of continents, there, necessarily, will be localized the greatest attracting force. Observations are not yet in accord as to the actual deformation of the ocean-level through this irregularly acting attraction, but it has been assumed by some that it might in some places amount to as much as 2,000 or 4,000 feet. In other words, the surface of the ocean may vary in its distance from the earth's centre by fully this amount. Whether it really does or does not must be left for more accurate researches to determine; but for our purposes it is sufficient to know that a variation in level, of whatever extent, does exist.

Another form of inconstancy in the oceanic waters is brought about in a different way. If, through whatever cause, a considerable part of the oceanic floor should be upheaved, and thereby contract the space that is normally occupied by the oceanic waters, there must necessarily follow a displacement of these waters, with an overflow on the land; we should then have a deluge, or *oceanic transgression.* If, on the other hand, a reversed action took place; *i.e.*, if instead of rising, the oceanic floor broke still farther within itself, or if, through the fall of an adjacent piece of continent, the basin was expanded laterally, — a condition that must have been imposed upon the Atlantic at the time when the Mediterranean area subsided, — then, of necessity, must there have been a contrary movement in the ever mobile waters. With a basin of enlarged capacity to receive them, they will withdraw from the land, and leave high and dry that which has before been covered; this condition has properly been called an *oceanic recession.* These are important facts to realize, since they open up a conception in geological history very different from the ideas that were generally held by the older geologists. They indicate that the evidences that have ordinarily been received as proving movements of the land in and out of the water may at times, and perhaps most often, have been in reality only the proofs of water-movements, and that the waters cover a perfectly stable land-surface.

Drowned Lands and Waters. — When a land area, of whatever extent, becomes submerged beneath the oceanic waters, whether through its own subsidence, or through a rise in the level of the sea (oceanic transgression), it becomes properly a *drowned land.* Pieces of drowned land are familiar objects to the inhabitants of many portions of the eastern border of the United States, and perhaps most so in the State of New Jersey, where the encroaches of the sea have been carefully studied and plotted. Patches of meadow-land lie here and there covered by the sea, and in places the remains of the old foresters can still be seen rising out of the invading waters. The same condition is to be found along many parts of the British coast, in the south of the Scandinavian peninsula, along the Bay of Fundy, etc. A large portion of the lowlands of Belgium and the Netherlands would be drowned lands were they to be deprived of their protecting dykes, since they occupy a level that is actually lower than that of the sea. How far the submergence in these cases was brought about by a *positive* movement of subsidence on the part of the land, or through an oceanic transgression, remains yet to be determined. In the absence of a knowledge that will permit us to determine a question of this kind, it has been found convenient to use the terms "submergence" and "apparent subsidence," in preference to simple subsidence, to indicate for the land its lower placement relative to the sea.

The continental shelf, as has already been stated, is by many geologists considered to be a submerged extension of the continent which it immediately adjoins. A certain amount of strong evidence supporting this view is found in the fact that over parts of this shelf deep furrows find their way in more or less regular lines to the deeper sea, and landward connect with estuaries of existing rivers. One such is found continuing oceanward from the mouth of the Hudson River for one hundred and eighty miles or more, and marked off not far from its termination by a depth of its own of some eighteen hundred feet. Another continues the estuary of the Delaware; and still others, perhaps less positive in their relations, are believed to represent the St. Lawrence and Susquehanna. These sub-oceanic furrows, seeing how closely they stand in relation with the land-waters, have naturally been assumed to be of river formation, and to have been made at a time when the rivers, with greater extension oceanward, were flowing over dry land, and with a fall sufficient to excavate the deep channels. If this is their true interpretation, then they are strictly "drowned channels." We are probably even justified in considering the long tidal reaches of some of our rivers as "drowned rivers;" for they, too, have seemingly been invaded by the sea. The lower course of the Hudson, for some sixty to seventy miles above its mouth, flows over a drowned channel, for the river of itself could hardly have excavated below sea-level; and the channel that it now occupies, with a depth of fifty or sixty feet, must have been cut when it stood at a level above that of the sea. The same is true of the estuary of the Delaware and of the Susquehanna, and, in fact, of every stream the depth of which is considerably greater than that of the outlying waters.

Fjords; Strands and Ocean Terraces. — One of the most marked characteristics of northern border-lands is the number of rock and mountain prominences which project into the sea, and include between themselves continuations of land-valleys — the fjords. The coasts of the Scandinavian peninsula and Britain (particularly of Scotland), of Maine, Newfoundland, Labrador, and Greenland are distinguished by fjord ("frith," "firth") structure. In most cases, probably, the fjord is merely a submerged mountain valley; for in all its special characteristics it bears the imprint of the valley that continues it on the land. Soundings, too, indicate a gradual continuance of the floor of the land-valley beneath the sea, or into that portion which is strictly drowned. Most fjord-valleys appear to have been fashioned more or less extensively by glacial ice, a circumstance that explains why by far the greater number of fjords occur in regions of existing and past glaciation.

In evidence of the relative rise of the land are the numerous elevated ocean beaches or "terraces" which accompany certain coast-lines. These are the counterparts of the terraces that we have found to border inland lakes, and they tell the same history of a withdrawal or lowering of the waters. Marine terraces frequently occur, four, five, or six, placed one above the other; and they usually follow with marked horizontality the surface level of the sea. They are the ancient beaches, and to the highest of them the ocean at one time reached; in some regions they constitute the country roadways, and are known as "strands." (Plate 21, Fig. 2.)

Wear of the Shore-Line; Plain of Marine Denudation. — Wherever the waves and cutting surf impinge upon the shore-rocks, they begin the work of destruction; and this work continues until the land-surface has been reduced to the form which makes the "bite" of the waves no longer possible. So long as cliffs or bluffs remain, the sea continues mercilessly to batter them down; they are undercut and toppled over, hammered into by the flying fragments of rock that the sea itself tosses up, or wedged apart, where, in narrow sluice-ways or races ("ovens," "kitchens," "blow-pipes," and "blow-holes") the surging waters acquire increased violence. Everything yields sooner or later; and the sea follows its conquest by quietly levelling all to the ignoble form of a gently undulating plain, — the *plain of marine denudation*. Far into continental territories these plains of denudation extend, and teach us the lesson of oceanic transgressions and recessions.

Plate 21.

1.

2.

OCEANIC DESTRUCTION.

1. Marine arches on the northern coast of Ireland, the work of to-day.
2. The island of Torghätten, west coast of Norway, with a blow-hole cut through the rocks by the wash of the sea. The hole is now upwards of 400 feet above sea-level, and thus indicates a displacement in the relative levels of the sea and land.

Although monotonous in aspect, they are as imposing monuments of past work, of past activity, as are the peaks, pinnacles, and castles that have been worn out of the dry land by the atmospheric waters. The first tendency of the oceanic waters is to level all inequalities to a uniform surface; the first tendency of the atmospheric waters is to break up all regular surfaces into inequalities. The work is in opposite directions; but it all tends to a single direction in the end, the monotonously uniform plain, — peneplain or plain of marine denundation, whichever it may happen to be.

The Dismemberment of the Land by the Sea. — The rate at which oceanic destruction takes place depends naturally upon a number of distinct conditions, not the least important of which is the constitution of the rock-masses that are being acted upon. Soft rock goes much faster than hard rock, and loose and incoherent materials still faster than soft rock. On some parts of the English coast, slices of land have been taken out at the rate of three feet, or even more, in a single day; and in comparatively short periods the very sites of towns and villages have been completely lost to the sea. Peninsulas are converted into islands, islands are cut in twain, and the fragments further parcelled out into solitary rocks and rocklets. The Hebrides, Shetlands, Orkneys, are all parts of what at one time was the mainland of Britain, just as Great Britain and Ireland are in themselves only dismembered parts of a formerly united Europe. The rocks and islands off our northern New England coast record the same story, as do the ocean-bound cliffs and ledges of Nova Scotia, Newfoundland, and Labrador. (Plate 21, Fig. 1.)

It is not always easy or practicable to determine just what loss an extensive land-mass suffers through such oceanic destruction: some parts unmistakably suffer in the complete, or almost complete, loss of their material; but, again, others gain through the wash of this material to them. Despite the terrific destruction that is taking place in many parts of the British coast, it seems doubtful if the areal surface, taken in its entirety, has lost anything in a period of nearly 2,000 years. The wash of one part has accumulated in another, and thus a certain measure of compensation has been meted out. No one who has not seen the ocean in its full fury, nor any one who knows it only in regions of flat sea-beaches, can conceive of the energy that is put into the destroying power of its waves. These in themselves rarely rise higher than thirty-five or forty feet; but where they meet the vertical cliffs their waters are frequently hurled five times higher, and they are known to have been tossed to three hundred feet, and to do execution even at that height. Blocks of rock weighing from ten to twenty tons have been washed together by the angry waters at elevations of fifty or sixty feet above the sea; and it is claimed that a mass of concrete weighing one hundred and twenty-five tons was moved three feet over its bed in the harbor of Cette, France. Downwards into the sea itself the work continues, churning up the bottom to a hundred, two hundred, or perhaps even three hundred feet. And yet, with all this, the destruction worked by the ocean probably falls far below that which has been brought about by the atmospheric waters and the running waters of the land.

The Ocean as a Receiving Basin. — A short time ago I stood upon the great bridge that spans the Mississippi River at St. Louis, and looked down upon the "Father of Waters" slowly rolling its course to the open sea. The water was at a low stage; and on either side stood out dreary expanses of mud-flats, a portion of the flood-plain of the river. For miles before approaching the stream on the Illinois side we travel over similar flat reaches of ancient flood-plain, with the boundary hills well within the country. Apart from the fact that it was the Mississippi River, and that the mud it carried away with itself was a part of American soil, there was nothing specially attractive about the picture; and probably it was not nearly so inspiring as some would have wished. But it awakened within me the reflection: What does it all mean?

Ages ago, where the stream is now flowing, there was ocean, the same ocean to which the river is to-day pressing forward its mud sediment. The configuration of the rocks declares it to have been so; the landscape shows it. At that time the American continent was perhaps divided into two halves, with the waters of the Gulf of Mexico extending far into British America, and to the very base of the western mountains. Let any one visit the delightful Colorado Springs, and look south along the line of the Rockies, and it will not take him long to recognize, in the gently sloping country that rolls off eastward in the direction of the Mississippi, the ancient floor of the sea, — much of it still as perfect as if it had been laid dry only yesterday. Gradually the land lifted, the waters were called off, and the country was united into a single whole. Over this ancient floor of the ocean now flows the Mississippi.

The Sediment Discharge of Rivers. — If we take a certain quantity of this St. Louis water and weigh it, together with an equal quantity of pure water, we shall have no difficulty in ascertaining just what proportion of impurity is held in suspension by the water, — in other words, how much mud is distributed through every gallon-measure of the river. And if over a given line we can calculate how many gallons of water are being passed by the river in any definite period of time, whether week, month, or year, it becomes an easy computation, by the simple rule of multiplication, to tell just how much sediment is being swept along in the same space of time. With a point of observation placed nearer to the mouth of the river, or below its last tributary, we should by the same process be in a position to estimate the total amount of sediment that was being gathered in from the entire Mississippi basin, inasmuch as the main stream and its tributaries are the arteries of drainage for that basin. This has been done, and it is shown that the river actually discharges every year not less than 7,500,000,000 cubic feet of solid mud material.

What is the significance of this enormous discharge? It means simply that this amount of material, if spread out and evenly distributed over the floor of the Mississippi basin, would elevate that floor (making the necessary allowance for compacting into rock), by $\frac{1}{60}$ of a foot in a century, or by one foot in six thousand years. To state the proposition in a reversed way, the river with its tributaries removes from all parts of its drainage basin, on an average, one foot of solid material in every six thousand years. Now, if we assume that all the rivers of the continent are doing an equivalent amount of work in their own drainage basins, then must the entire continent be losing material to an amount equal to a uniform surface of one foot in thickness, covering its entire expanse. By several methods of calculation it has been determined that the average elevation of the continent, with its mountains, plains, and hollows, is approximately 1,200 feet; therefore, were there no counteracting influences, the whole surface would, by the method of denudation that has here been outlined, be washed down to the sea-level in a little over 7,000,000 years. In reality, the time would not be so long; as the amount of destruction that has been calculated does not include the materials that are removed invisibly through chemical solution, and which probably amount to a full twenty per cent of the materials carried out in mechanical suspension.

The Making of New Land.—We ask ourselves: To what end does all this material go? The region of the mouth of the river, where the several "Passes" are forging their way into the Gulf, gives the answer to this question. It is there that the river-mud has already accumulated to a depth of 700 feet and more, and from there it is transported by various currents to different parts of the continental border. The Ganges is doing much the same for India, the Nile for Africa, the Amazons for South America, the Rhine, the Rhone, the Po, etc., for Europe. Behind deltas, in front of deltas; in estuaries, out of estuaries,—the sea is being filled in. Islands, bars, sand-strips, and lagoon-barriers are being formed; and between them and the main coast new strips of territory are created. In this way the continents grow and expand, only to be worn down and destroyed elsewhere. Ravenna, which during the Roman period was situated on the shores of the Adriatic, is now removed through the outward growth of the Italian peninsula four miles from the sea; Ostia, the former port of Rome, is to-day an inland city, with a land-strip of three miles separating it from the Mediterranean. And the fate of these two cities threatens Venice, looking towards a future not very distant.

Many of the finest alluvial lands of the world are the joint product of river down-wash and oceanic reconstruction. The fertile plains of Lombardy, Piedmont, and Venetia represent in the main a former bight of the Adriatic, which has been filled in by the *débris* that has been washed off from the southern face of the Alps; the great jungle plains of Northern India, which run up to and skirt the base of the Himalaya chain, are in the same way only an infilling, with the materials derived from those mountains, of a portion of the former Indian Ocean. The peninsula of India is to-day a part of the Asiatic continent, but in past periods its heart was distinct and far from the northern land-mass. The ocean is thus the great accumulator of sediments, and the source which furnishes the new materials for the building up of the continents. In it the new rocks are formed, and not only from the loose sediments of mud, sand, and pebble, but from the invisible lime which is carried out in solution by the terrestrial waters, and in the ocean separated by vital agencies into the hard parts of shell, coral, etc.

CHAPTER IX.

THE EARTH IN ITS INTERIOR.

THE text-books of a quarter of a century ago, and some of them even to-day, tell us that the earth is a hollow shell, filled nearly to the surface with fiery molten material. The hard crust, so-called, was frequently assumed to be not more than forty or fifty miles in thickness, and sometimes even less. The reasons that were given in support of this conclusion can be summed up in a few words: Volcanoes throw out molten material from the interior; a steadily increased heat is known to follow every descent into the earth's interior; the crust shows prodigious movements, which can only be explained on the assumption that the mass is freely suspended or floated. The objections that if the earth were this thin shell it would yield to the same kind of deformation which is imposed upon the oceanic waters through solar and lunar attraction; and that the inner fluid material might in itself make "tides," and from time to time disrupt its enclosing walls, — were not considered, certainly not in their proper significance. The researches of to-day show almost conclusively, and to most physicists perhaps conclusively, that the *planet is virtually solid to the core*, and that it bears itself with the rigidity of steel or glass. This conception, which is so fundamentally opposed to former notions, is based primarily upon a rigid mathematical determination; and there are no facts in geology that are opposed to it.

The Internal Heat. — Every one who has descended into a deep mine, where the cold outside air has not been introduced by blowing fans, knows how much warmer it is below than above; if the mine is very deep, the heat is all but unbearable, and for working purposes practically so. At 3,000 feet, or a little more than half a mile, the temperature in our coal-mines would be uniformly about 100° F., at 5,000 feet nearly 150°. Over the entire earth, barring some specially exceptional spots, there seems to be a steady increase of temperature of approximately 1° F. for every 50 or 60 feet of descent. Occasionally this amount is increased to about 1° for every 35 feet, and about as often reduced to 1° in every 75 feet. A recent boring in the Lake Superior region gives, very exceptionally, an increase of only 1° for about 200 feet. The steady increase begins at that point beneath the surface which marks the farthest penetration of the heat-rays of summer and the cold of winter, — in other words, where there is an equable temperature the year round, and where this temperature marks the annual average for the locality that is immediately above it. Such a spot is generally found at a depth of not more than 60 or 80 feet beneath the surface.

With a steady increase beyond this point of 1° F. for every 50 or 60 feet, it takes no very great depth to give a prodigious amount of heat. At 10,000 feet in the latitude of New York or Philadelphia, the temperature would be that of the boiling-point of water; and at thirty miles, 3,000°, or about sufficient to fuse, at the ordinary melting-point, the most refractory substances known to us. The melting-point of gold is about 2,500° F.; of platinum about 3,200°. It is the recognition of this fact, and the knowledge that very much higher temperatures must exist still farther within the interior, which gave such strong support to the notion of internal fluidity; for, it was argued, no substance, unless it was of a character that is now entirely unknown to us, could withstand the enormously high temperature of the deep interior without either liquefying or volatilizing. The condition here indicated is not, however, borne out by the facts. When we subject a body to a high degree of pressure, we at the same time materially raise its "melting-point," or point of fusion. What would under ordinary conditions melt at perhaps 200°, may not with this pressure imposed upon it melt at less than 250°; and under still greater pressure, it may only melt at 2,000°, or perhaps not at all. The earth's mass reacts upon itself with such enormous pressure, that it is by no means unlikely that the greater number of substances within the interior do not melt, even at temperatures of 4,000° or 5,000°, simply because they cannot obtain release. This is an important condition, and it permits us to harmonize the behavior of the different substances of the interior with the conception and mathematical determination of a rigid interior.

It has not yet been determined what is the greatest amount of heat that is to be found in the earth's interior. It has been shown by Sir William Thomson that beyond a certain depth, of perhaps 80 to 100 miles, the increase is a rapidly diminishing one, and it is probably not straining the truth when it is assumed that the warmest temperature need not exceed 7,000° or 8,000°. Many people believe that this great heat has much to do with determining climate, giving to the surface a generous distribution of warmth, and so forth; as a fact, its influence is not felt on the surface at all, not even to the extent of melting in the course of a full year a sheet of ice of a millimeter in thickness and covering the globe. Nor does it seem to have affected the climate in any of the past geological periods, except, possibly, in the very earliest.

Pockets of Molten Material.—It is not natural for all persons to conceive alike of this condition of terrestrial solidity. Those who live in the neighborhood of active volcanoes do in truth see molten material thrown out from the "bowels of the earth;" this is certainly evidence of internal liquidity of some kind. There are, however, a number of causes that can work toward liquefying portions of the interior without thereby sensibly affecting the greater mass. We do not say that iron is not solid because it contains a number of air-bubbles; nor is ice liquid when its mass is riddled with air and water holes. In the same way, the earth may have, and doubtless does have, pockets of liquid or molten material, and perhaps even a complete shell of it, underlying the surface at no very great depth; and yet the presence of such "filled vacuities," being insignificant in area as compared with the entire mass, would not sensibly disturb the argument for solidity. Of the ways in which such volcano-feeding pockets may arise, it is only necessary to enumerate one or two.

Proximity to a field of special chemical activity, where chemical alterations and new combinations are carried forward with particular energy, and where through such processes there is liberated an extra quantity of heat, may bring about local liquefaction. Again, the same result may follow from the simple operation of removing a portion of the pressure that keeps down liquefaction, — a sudden lifting off, as it were, of a portion of the melting-point, — whether through rock displacements, the absorption of rock material through chemical solution, or otherwise. And probably there are many local spots scattered through the earth where the added pressure is not sufficient to overcome the added temperature, and where consequently the rock appears molten.

An abundant proof of the rising temperature within the earth is brought to us by the numerous thermal springs which issue at the surface. They acquire their special temperatures by traversing the heated regions below; and their own heat is the index of the depth to which they penetrate, or whence they arise. The greater the penetration, the more highly heated will they come to the free air; some of this acquired heat is lost in the passage of the spring-waters to the surface, but enough is retained to permit of a fair estimate of the depth whence the water has risen. In some regions, especially in the vicinity of volcanoes, a high temperature may be acquired as the result of simple contact with chemically heated bodies, and entirely independent of the matter of depth.

The Density or Weight of the Earth. — There is no possibility of finding out to what extent the deeper rocks of the globe differ from, or agree with, those that are known to us at the surface. By various methods of computation it has been determined that the average weight of the earth's materials is about 5.5 times that of water, and about double that of the superficial rocks. This being the case, it must follow that much of the interior has a density at least 7 or 10 times that of water, and not impossibly of 15 or even 20 times. It has accordingly been urged that probably the deeper parts are largely metallic in nature, or even pure metal. But it cannot be overlooked that, under the strain of the earth's enormous pressure, even the ordinary superficial rocks, whether granites, sandstones, or limestones, might be so well compacted as to have their normal hardness far exceed that which belongs to average rock. Yet it is by no means impossible, or even unlikely, that vast metallic deposits do occur within the deep interior.

Plate 36.

VOLCANIC PHENOMENA.

The volcano of Fusiyama, Japan, a symmetrical and typical volcanic mountain.

CHAPTER X.

VOLCANOES, AND WHAT THEY TEACH.

The Aspects of a Volcano; Vesuvius.—Text-books of geography ordinarily describe the volcano as a mountain that "throws out lava, fire, and smoke." Were you to saunter out of a quiet morning along the shores of the Bay of Naples, and cast your eye back to the landscape which bounds the ocean to the east, you would observe, rising up in its own peculiarly graceful form, a mountain that differs essentially from the ordinary mountains to which we have become accustomed. Vesuvius rises with a gentle sweep from near the sea, its slope so gradual at first as hardly to give it the appearance of a mountain. Farther on, the steepness of slope rapidly increases; and for about the last 1,500 feet of vertical height, the rise is so rapid that the mountain may be said to go up like a "cone." At the summit we have reached an elevation slightly exceeding 4,000 feet. Could this mountain be divested of all the surroundings that do not properly belong to it, it would present much the same appearance from all points of the compass as it does from the ocean-side, —a characteristic of uniformity that belongs to nearly all perfect volcanoes. When I visited the mountain a few years ago, the top was occupied by a great depression or pit, of possibly 300 to 400 feet diameter, and

80 or 100 feet in depth, from the bottom of which issued vast curling wreaths of heated vapor, and more or less frequent showers of red-hot, and nearly white-hot, rock-material, — "cinders," as they might perhaps properly be called. I descended into this great depression, or *crater* as geologists call the hollow, and cautiously approached the centre, where nearly all the active work was going on. The rock-floor over which my steps were directed was glowing in places with red heat, and it did not take much study to tell me that there was little between the soles of my boots and a seething, fiery mass below. It was a thin crust, but sufficient to hold me. Somewhat to one side of the centre of the crater there was a diminutive mound-like elevation or "conelet," hardly more than four or five feet in elevation; and from it was issuing all that tumultuous vapor and flying rock which I had observed from the crater-rim. (Plate 37.)

The Operations of a Volcano. — From my position near the base of the conelet the operations of the mountain could be easily followed. A great explosion of steam would sometimes be accompanied by a liberal outpouring of red-hot cinders, and less often by an actual outflow of the molten material in mass — the *lava*. Frequently the liberation of steam was unattended by outpouring of any kind, but was followed by a sound like rolling thunder, ending with a "thud," as though something massive had fallen to the bottom. With a little courage added to my desire for study, and with the wind blowing well over my back, I ran, at favorable moments, to the top of the conelet, and looked into the furnace below. Now and then,

Plate 37.

1.

2.

VOLCANIC PHENOMENA.

1. The cone of Vesuvius, with lava-fields at its base. V. A parasitic cone. N. A lava-plug, marking the site of a former channel of eruption. C. Scoriaceous lava. R. Ropy lava, showing lines of flow.

2. The brink of the Vesuvian crater.

Plate 38.

1.

2.

VOLCANIC PHENOMENA.

1. Cascade in the lava-flow from Kilauea, Sandwich Islands, in 1880-1881.
2. Termination of lava-flow from Mauna Loa in 1880-1881.

through the dissipating vapor, the glowing material which formed cinders and lava was easily distinguishable, and the eye could follow without difficulty its ascent through the funnel or neck of the volcano. When the pent-up vapor had sufficient force within itself to elevate the seething lava, it would throw it out; at other times it broke through the confining *magma*, and allowed it to fall back to its interior home. A repetition of these performances constituted the volcanic action of a volcano. There was no smoke, there were no flames. At the present time the large crater no longer exists. The activity of the little cone has completely filled it up with its ejected material; and the volcano is flat-topped, with its working conelet perched on this summit.

The Characteristics of a Volcano. — Vesuvius is the type of by far the greater number of volcanoes of the earth's surface; they may, therefore, be described as conical mountains which are, or have been, active in throwing out molten material, whether in fragments (cinders, ashes) or flowing streams (lava), from the earth's interior, the ejecting process being usually accompanied by the liberation of vast quantities of the heated vapor of water (steam). Our definition differs from the ordinary geographical one in eliminating the matter of smoke and fire; the former is only the quietly curling steam, and the latter the reflection of the heated mass below on this vapor, and on the clouds of ashes that go up with it. No volcano has yet been found that truly smokes, as the combustion is not of such a nature as to produce smoke; and it is only in most exceptional cases that flames have actually been seen in a crater or issuing from it. When they do occur, as for example among the volcanoes of the Hawaiian Islands, they represent the combustion of hydrogen gas.

The closer examination of the outside of a volcanic mountain, such as Vesuvius, shows it to be a more or less regular agglomeration of the materials of eruption. Extensive lava-beds radiate from the central parts; and between them are heaped great quantities of thrown-out blocks and cinders (*scoriæ*), alternating perhaps with great thicknesses of extremely fine sand. Were we to slice the volcano from top to bottom, we should also find the same structure in the interior, the materials, possibly, bedded among themselves with a certain amount of regularity. If our section were made through Cotopaxi instead of Vesuvius, or through Etna, or Stromboli, we should still find the same structure, — which leads to the interesting conclusion that *volcanoes are built up through the materials which they themselves throw out.* The mountain may be ten feet high, or it may be ten thousand, but the fundamental structure is the same. (Plate 37, Fig. 1.)

Dimensions of Volcanoes. — The most striking differences that are to be found among volcanoes relate principally to size, to the contours of their slopes, and to the class of materials which they put out. The most gigantic active volcanoes of to-day are those of the Equatorial Andes, where several measure 17,000 to 19,000 feet in height. The passively active cones of Popocatepetl and Orizaba, in Mexico, are respectively 17,500 and 18,200 feet in elevation. Demavend, on the borders of the Caspian Sea, said by some to be fully 20,000 feet in height, may still be active; and the

Plate 39.

VOLCANIC PHENOMENA.

The floor of the crater of Kilauea, Sandwich Islands, with escaping vapors, after the breakdown of 1886.

Plate 40.

VOLCANIC PHENOMENA.

The volcano of Tarawera, New Zealand, a few days after the eruption of June 10, 1886; the vapor columns in the foreground occupy the position of (the former) Lake Rotomahana.

exceedingly active Mauna Loa, of the Sandwich Islands group, which rises 13,700 feet out of the water, may properly be considered as rising from the full depth of the ocean, nearly 17,000 feet lower; it is there that its base is implanted. The size of the individual parts of a volcano are in no way dependent upon the actual size of the mountain itself. Thus, while such a colossus as Popocatepetl has a crater not more than two-thirds of a mile across, the cup of Kilauea, a mountain of Hawaii barely more than one-fourth the height of Popocatepetl, measures nearly three miles in greatest diameter; and the crater of the moderately elevated Aso-San, one of the very numerous Japanese volcanoes, exceeds these dimensions by fully three times. Again, the rather insignificant Skaptar Jökull, of Iceland, has on more than one occasion thrown out lava fields of from thirty-five to fifty miles in length; whereas, in the case of many much larger cones, the lava outflows have never reached twenty miles, or in fact, half this length. (Plate 39.)

Composite Cinder and Ash Cones. — So far as the materials of discharge are concerned, there is a vast difference between them. In the case of the volcanoes of the Sandwich Islands group, the material of the lava is so fluid or "glassy," and there is so little paroxysmal discharge of steam, that the outflowing sheets take long and easy courses, and thereby give a gentle and open contour to the mountain; the gradient for much of its course is not over three degrees, and hardly in any place exceeds fifteen degrees. (Plate 38.) Elsewhere the lava has a much firmer consistency, flows heavily, and solidifies at comparatively steep angles; the slope thereby increases to twenty, thirty, or even thirty-five degrees; and where the lava is exceptionally tough or "viscous," its solidification may take place even at angles approaching verticality. Some volcanoes rarely give out anything but lava; others discharge lava and cinders, or ashes, as the case may be; and from the proportional quantity and quality of these materials we distinguish "composite cones," like Vesuvius, — where lava, scoriæ, and ashes all unite to make the mountain, — "lava-cones," "cinder-cones," etc.

Lava (Basalt), Scoriæ, and Ash. — Lava is almost invariably a hard and tough rock, of a dark gray, green, black, or nearly black color, which on decomposing frequently turns rusty-orange or purplish-red. Most varieties are fine-grained, or compact without visible grains; others are translucent, glassy (*obsidian*). *Trachyte*, one of the varieties, receives its name, "rough stone," from a characteristic which distinguishes several other varieties as well; *basalt*, also known at times as greenstone, *dolerite*, and trap, is generally an ancient outflow, excessively tough and finely grained, dark in color, and weathering with a rusty coat. It occurs often in a columnar form, "basaltic structure," like that seen in the well-known Giant's Causeway of Ireland, in Fingal's Cave of the Island of Staffa, and in many hardly less remarkable localities in the United States. (Plates 42, 43.) Most lavas exhibit in parts of their substance innumerable holes or cavities, usually elongated one way, through which the escaping steam gained the exterior. This "blistered" structure, so much like that which is seen in furnace slag, is also found in the fragments that have been blown out from

Plate 41.

VOLCANIC PHENOMENA.

The solfatara of Whatipoho, New Zealand, showing extensive rock incrustations.

the main mass of the lava, and which now constitute the so-called cinders or *scoriæ*. These when, through rubbing or further powdering they have been reduced to a fine powder, constitute volcanic *ash*. Pumice is only a glassy form, in exceedingly light weight, of volcanic cinder. It should be noted here that the article known to jewellers as lava is in most cases only a hardened paste or cement of ash and water, a puzzuolana or *tuff*. The material which covers Pompeii is largely of this nature.

The Working Activity of Volcanoes. — Sometimes a single eruption marks the entire history of a volcano. More generally a number of eruptions follow one upon another, the intervals of quiescence being very irregular, ranging from a few months, or even weeks, to years and centuries. It is often difficult to tell just when a volcano is "extinct," since an eruption might at any time suddenly remove the dormancy which had been supposed to mark extinction. There are a few volcanoes, such as Stromboli in the Mediterranean, which are continuously active. Vesuvius has itself been in eruption a part of almost every year for the last period of nearly a quarter of a century; but through the past eighteen hundred years, or since the great eruption of A.D. 79, which overwhelmed Pompeii and Herculaneum, there have been long intervals of repose. The intensity of eruption depends, to some extent, upon the length of time that the mountain has remained passive; or, what is probably nearer to the truth, upon the firmness with which its parts have been sealed and "plugged" up during the period of repose. The tightly fitting lava that, on the cessation of activity, has solidified as a plug in the neck of the volcano, keeps down for a while the energy that is boiling below; and when the eruption finally comes, if it comes at all, it may present itself in a true paroxysm. (Plate 40.)

In a number of cases it is believed that the whole top of a cone has been blown out by a sudden explosion of this kind; the mountain is said to have been "gutted." In the great eruption which took place in the Sunda Sea in August, 1883, the small island of Krakatao, lying off Java, was literally shattered to pieces, and almost all of it disappeared beneath the water; only fragments indicated the former position of the crater. Even in the case of Vesuvius, it is frequently assumed that the eruption of A.D. 79 blew off the top of the volcano which produced the mischief: it is certain that the Vesuvius of to-day is not that mountain, even if it stands on nearly the same spot; for surrounding it, in massive rock-walls, are the fragments of its ancient predecessor, quiet with the repose of the centuries. Locally these parts of the old crater wall (*crater-ring*) are known as Monte Somma. After the long interval that has followed an eruption of this kind, it is not easy to ascertain the precise order of events as they presented themselves, and some geologists hold as questionable the opinion which ascribes decapitation to the mountain; they prefer to believe in the collapse or "infalling" of the top of the volcano, and there is no question that this condition often follows a violent explosion. The eruption loosens the interior, and paves the way for a subsidence.

Shifting of the Points of Activity; Parasitic Cones. A long period of dormancy in a volcano frequently

Plate 42.

1.

2.

VOLCANIC PHENOMENA.

1. The trap-dike of West Conshohocken, Pa., where the hard and resisting rock cuts through the hydro-mica schist.
2. The "steps" and columns of basalt of the Giant's Causeway, Ireland.

Plate 43.

VOLCANIC PHENOMENA.

An exposed face of Orange Mountain, near Orange, N.J., showing basaltic columns; the mountain is a product of fissure eruption, a "trap" wall.

leads to the breaking through in a new place of the next eruption; geologists speak of the "travelling" of the seats of activity. In Etna, for example, the active points have shifted numerously since the beginning of the Christian era. In addition to the main central opening, the mountain is provided with a large number of secondary openings, set in little monticules of their own, the so-called *parasitic cones*. These afford release from the strains of the interior in the same way that the principal opening does, and through them large quanties of lava and ashes are thrown out. The eruption of 1886 from the Monte Gemmellaro, a parasitic cone on Etna, sent out a lava stream the dimensions of which were estimated at sixty-six million cubic metres. Whether or not these accessory cones are fed from a main single channel of lava running up approximately to the centre of the volcano, or from independent sources of their own, can only be determined from a dissection of the mountain. But whether one way or another, the masses of lava that have hardened solid in all the passages stand like the branches of a tree, penetrating the mountain in all directions. They are the volcanic "dikes" of geologists. (Plate 37, Fig. 1.)

The After-History of a Volcano. — The volcano may have served its time; life has left it, and it begins to decay and crumble. In place of the boiling crater, which, if not always active, was at least always threatening with possibilities of activity, we have a peaceful hollow, now perhaps put to the humble but useful labors of man. The swarthy Mexican Indian may frequently be seen furrowing with his rude ploughshare the soil that once quaked and trembled with the energies that were stored up beneath it. The crater was his field — a smiling garden of aloe or sugar-cane. The beautiful lakes of Central and Southern Italy — Albano, Nemi, Bolsena, Bracciano, Avernus, Fusaro — are the eyes of ancient craters, reflecting to-day, not the fire of the interior, but the quiet of the Mediterranean sky. The Balaton of Hungary is another of these *crater-lakes*, as is also the not inappropriately named Crater Lake of Oregon. High up in the Nevado de Toluca, of the Mexican plateau, fourteen thousand feet high, is one of these "eyes of the sea," one of the loftiest of all known lakes. All these beauties of nature are, however, doomed to destruction.

The mountain continues to wear; its slopes are furrowed by running and tumbling brooks and cascades; the very core is reached; and for a time perhaps nothing stands but the great central plug of lava — the *neck* or *chimney* — around which the energies of the volcano were centred. (Plate 44.) It stands grimly out of the landscape, reading for it a history that is not less interesting than it is ancient. It is not a matter of a few years over which this destruction has taken place, but of centuries and of tens of centuries. Further yet the destruction continues, until, possibly, time has levelled all, and effaced the history. We then search for the record in the rock-masses about, and perhaps find vast heaps and deposits of volcanic ash and cinders, of giant lava beds, scattering over the country. They may live long after the mountain which gave them birth has itself disappeared; but in course of time they, too, will go. Far and wide over the earth's surface we meet with the evidences of vulcanism, of

Plate 44.

VOLCANIC PHENOMENA.

"Mato Tepee," or "Bear Lodge," Wyoming, a basaltic tower, 625 feet in height, the remains of an ancient lava injection which was forced upward through sedimentary strata, now removed by erosion.

volcanic energy that has spent itself ages ago, or of such as has only recently passed to slumber. Probably at no time in the history of our planet since the first rock was formed has there been an absence of volcanic action; and unmistakably during certain periods of this history the activity was much more pronounced than it is to-day.

The Causes of Eruption. — This is as yet an unsolved problem. The presence of water at the seat of volcanic action, and the conversion of water into its expansive and explosive form of steam, have generally been considered to be the conditions that bring about eruption, and without which it has been assumed there could not be much of it. Many difficulties connect themselves with this explanation, not the least among which is the fixed positions which the volcanoes occupy, and the fact that water could only be an active agent in the work when the material for this work had already been prepared for it. While, therefore, water and the vapor of water are unquestionably associated with volcanic phenomena, and may even be directly instrumental in bringing about certain of their phases, it seems more in accordance with the succession of events to consider them as secondary rather than as primary causes. It is by no means unlikely that *much of the pushing and upheaving of lava is due to contractional impulses of the great mass of the crust* — a squeezing-up, as it were, of the fluid matter of the interior at points where this fluid material is most abundant, and where the strain of compression can be least resisted. Such areas, or points of least resistance, — areas of weakness they might be termed, — we have a right to search for along the troughs of the different oceans, and on the border-land of the continents and oceans. It is in truth in such regions that we find almost the entire force of volcanic activity to have concentrated itself.

Fissure Eruptions. — As bearing upon the possible or probable squeezing up of the molten material of the interior through crustal contraction, instances may be cited where vast quantities of lava or basalt are known to have appeared at the surface, not in isolated crateral patches, but in long lines of fracture or fissure, and without the accompaniment of those fragmental discharges which are associated with eruptions of the ordinary kind. These *fissure eruptions* have at times been continuous over lengths of fifty and a hundred miles, or even more, the lines of breach being often as regularly direct as though they had been artificially cut. In some cases the fissures are only a few feet in width, at other times they broaden out to respectable dimensions; but in one way or another they have thrown out an enormous amount of material. In the Northwestern United States — in Oregon, Washington, Idaho, etc. — and in India there are hundreds of thousands of square miles covered by the overflowing sheets of lava issuing from such fissures; minor fields are found in various parts of Great Britain, in Ireland, in France, etc. In the Eastern United States a number of long, low ridges — such, for example, as the Orange Mountains of New Jersey, the nobly picturesque Palisades of the Hudson River — are merely erupted masses that stand over the fissures through which they were extruded, and from which they have gently flowed off to one or both sides. The less resisting rocks through which they forced their way to the surface having worn more rapidly, they now stand out from them as prominent walls or buttresses, the *dikes* of geologists. It is customary to give to the ancient fissure-rocks the name of "trap," meaning step, from the circumstance that the rock most generally presents itself in step-like masses. Columnar structure is ordinarily a distinctive feature of trap, which includes among its varieties the basalt of the Giant's Causeway and Fingal's Cave, to which reference has already been made. (Plates 42, 43.)

Laccolites. — It has not yet been ascertained in what manner the fissures giving exit to this vast amount of lava were formed. In many cases, probably, they opened as the result of straining pressure from the interior lava itself; at other times it would seem that there was a gentle parting of the earth's crust, and that through this parting (or fissure) lava quietly welled out, and then overflowed in running sheets. It looks as if the Palisades of the Hudson River may have been formed in this quiet way. There are, however, unquestioned cases where the interior lava has, under the influence of crustal pressure, found relief in raising or "doming" up the rock-masses that lie above it. In this way it rears a mountain, and without showing itself at the surface. Thousands of feet (in thickness) of rock-strata have been made to yield before this irresistible strain, a feature in the landscape most beautifully shown in the La Sal and Henry Mountains of Utah. Upheaved mountains of this kind are known as *laccolites.*

CHAPTER XI.

DISTRIBUTION OF VOLCANOES AND EARTHQUAKES.

Distribution of Active Volcanoes. — The most cursory examination of any map on which the volcanoes of the world are plotted shows their distribution to be in close correspondence with the position of the ocean. There is hardly a volcano to-day which is removed two hundred miles from it, and there are very few that are at as great a distance. A belt closely circumscribes the Pacific basin, following the Andean and Cordilleran chains of South and North America, and connecting through the Aleutian Islands with the volcanoes of Kamchatka, and with those of the disrupted islands which lie east and south-east of the continent of Asia — Japan, Philippines, Sunda Islands, etc. The most destructive centre of vulcanism to-day is the region of the Sunda Sea, following from Sumatra and Java to Celebes and the islands beyond. The Asiatic volcanoes alone number several hundred; but, with the exception of those on the peninsula of Kamchatka, there are few that are located on the continent itself. The best known of these are Ararat and Demavend. The Central Pacific has the great volcanoes of the Hawaiian Islands, besides less important ones among the many islands that dot the region of Polynesia. The course of the Pacific belt is continued through New Guinea and New Zealand, with a possible termination in Mount Erebus, on Victoria Land in the Antarctic regions, beyond the 78th parallel of south latitude.

The volcanoes of the Atlantic basin are mainly insular, and include, among others, Hecla and Skaptar Jökull on Iceland, the volcano of Jan Mayen, Pico in the Azores, the Pic de Teyde of Teneriffe, Stromboli, Etna, and Vesuvius; the last-named is the only active volcano which is to-day found on the actual continent of Europe. Kilimanjaro, Kenia, and the Peaks of Cameroon, are dormant cones of Africa, Mfumbiro and the cones about Lake Rudolph being the only active or half-active volcanoes of that continent.

Seemingly the loftiest of all known volcanic mountains, whether active or extinct, is Aconcagua, in the Argentine Republic, approximately 23,000 feet in altitude. Sahama, the Nevado de Sorata, Illimani, and Chimborazo, other Andean summits, closely rival it; while Cotopaxi, with an altitude of nearly 19,000 feet, gives to us the picture of greatest activity combined with lofty elevation. Mount St. Elias, in Alaska, which was formerly supposed to be a volcano, has been shown by recent researches not to be volcanic. Popocatepetl, Orizaba (or Citlaltepetl), and Jorullo are semi-quiescent volcanoes of the Mexican Republic; Colima and Choboruco, active ones. Within the domain of the United States there does not appear to be any fully active volcano to-day, but extinct or quiescent cones are represented in Shasta, Tacoma, Hood, and Baker (the last active as late as 1880?). Besides the volcanoes that are visible, or have actually come to light on the land-surface, there are doubtless hundreds of others that are buried in the sea, and that manifest their energies unseen to the world, except in so far as the products of eruption are cast to the surface. Much of the pumice that is floating about on the free surface of the ocean is undoubtedly the output of subaqueous volcanoes.

Earthquakes. — Earthquakes are generally associated with volcanic manifestations, and to an extent they represent identical phenomena. In a broad characterization they are merely tremors of the earth's crust, the movement that is due to a series of elastic pulsations or waves passing through it. A wagon passing over a roadway produces a slight earthquake, other causes produce larger ones, and there is probably no spot on the earth where earthquakes or earth-tremors of one kind or another do not take place. Manifestly where, as in volcanic regions, great disturbances in the rock-masses are the order of occurrence, it would be difficult to escape the making of earthquakes; for every dislocation, every break, must be the cause of some kind of jar. It is this frequent interdependence which has united in the popular mind the two types of phenomena.

It is not easy, and in most cases perhaps impossible, to assign a cause for any particular earthquake, especially if its occurrence is in a non-volcanic region. In some cases it may have been the result of a simple slip of rock at the surface, in the not very extensive manner of the ordinary land-slide; elsewhere this slip may have been the grandly imposing one (not necessarily visible to the eye, but imposing in its effects) of entire rock-masses, of different degrees of construction, sliding away from one another. Some of the earthquakes of the Atlantic border of the Eastern United States have been attributed by geologists, whether rightly or wrongly, to the slip of the loose materials of the coastal plain from the more compact granites beyond. The splitting of rocks within the interior must be a fruitful source of earthquakes; and perhaps we are justified in concluding that many of the most destructive earthquakes — such as those of Lisbon in 1755, of Caracas in 1812, of Ischia in 1883, and of Charleston, S. C., in 1886 — were due to this cause. All the rocks of the interior are in a condition of strain, and their release is the occasion of the propagation of a series of waves of elastic compression. The breaking in of parts of the crust through the removal from below of the supporting material, as in the fall of the roof of a cave, is still another cause of earthquake-making. The disaster in the valley of the Upper Rhone in Switzerland, in 1855, when the greater part of the town of Visp was destroyed, seems to have been the immediate result of a subsidence following the removal of the underlying lime and gypsum deposits through solution.

It would appear that by far the greater number of earthquakes, whether large or small, have their origin at only a moderate depth beneath the surface. Probably from ten to fifteen miles measures the depth for all, and in the case of many it is unquestionable that they originate still nearer to the surface. In the case of the Carolina earthquake of 1886, the depth of origin is assumed to have been about twelve miles; and from this point travelled out, in radiating lines, and at varying angles, the series of pulsations which reached in one or more directions to a distance of a thousand miles or more. It has been claimed for the tremors which accompanied and followed the great eruption of Krakatao, in 1883, that they were transmitted completely through the earth, or across a distance of upwards of seven thousand miles.

Passage of the Earthquake Waves. — We do not as yet fully know all the peculiarities and eccentricities which associate themselves with the transmission of earthquake impulses; indeed, some of the rules or conditions which appear to be firmly established in certain regions are reversed elsewhere. Thus, it is well known that in some parts the accumulation of loose material, as gravel, sand, or soil, is a bar to the passage of an earthquake, or at least tends to render its force ineffective; elsewhere, it is just this form of deposit, as distinguished from solid rock, which tends toward destructive results. But whether one way or another, it may be laid down as a rule that an earthquake, issuing from one class of deposits and passing into the other, will at the line of junction do its severest work. The difficulty of accommodation in the pulsating waves to new conditions seems to be that which brings about the disastrous result. The influence of mountain chains as determining and directing the passage of earthquake impulses has long been recognized; the waves pass with difficulty through (or across) them, while they travel readily along the line of their extension. Earthquakes of considerable intensity originating on one side of a mountain axis may be entirely inappreciable on the opposite side, even if removed only by a few miles. In the same way a void of rock material, such as may exist in the region of caves, is a bar to the propagation of waves of this class.

Intensity of Movement. — Judged by ordinary sensation the earthquake movement is an extensive one; we feel ourselves turned and twisted, houses fall and crumble, and the earth seems to sway up and down with considerable departure from the horizontal line. Yet it is certain that in by far the greater number of cases of even fairly severe earthquakes the actual earth movement, either horizontally or vertically, is a very insignificant one, not measuring more than a fraction of an inch. In the disastrous Neapolitan earthquake of 1857 the movement was determined to be from two to five inches. Our own exaggerated notions are the result of mental disturbance for the time, and therefore subjective in their sensation. It is true, however, that under exceptional conditions really extensive movements do take place, movements which may be of a differentially vertical nature, or purely lateral in their effect. Thus, it is thought to be beyond question that areas in both Italy and Greece have been dropped several feet as the result of earthquake action; and this condition has been noted even so recently as the year 1893, when the Phocian and Athenian plains were so rudely shaken. It is stated on fairly good authority that the region of Casalnuovo, in Calabria, Italy, dropped twenty-nine feet in the early part of the last century as the result of earthquake disturbance. Similar occurrences have been noted in the Philippines, in New Zealand, in the region of western California (also in the water-tract between it and the outlying islands), and in the middle Mississippi basin (1811–1812). Elevation at times, but less often, takes the place of depression; the western coast of South America is most generally appealed to for evidence in support of this condition, but it is still doubtful if the facts there revealed have been properly interpreted. Fissures of greater or less length, and of varying width, are a frequent accompaniment of earthquake action; sometimes they remain permanently open, but more generally their existence is only temporary. Sand and mud of various degrees of consistency are frequently squeezed up in the course of compression of the earth, and their appearance on the surface may give rise to local deposits of considerable magnitude.

Tidal Waves. — Following any extensive shock on the ocean-front is the transmission of an ocean or "tidal" wave, the intensity and magnitude of which will necessarily be determined by the violence and length of continuance of the concussion. The devastation caused by such earthquake waves, whose movement may be transmitted completely across the oceanic basin, is frequently far in excess of that which is produced directly by the earth movement itself; the waves following in the wake of the destructive earthquake of Lisbon, in 1755, broke over the town to a height of 30–60 feet above highest tide, while those of Lupatka (October, 1737) measured 210 feet. The waves which followed the Krakatao catastrophe, and impinged upon the East Indian coast, are said to have swept 43,000 persons out of existence. Singularly enough, the advent of an earthquake is at times heralded by a recession or withdrawal of the sea; such was the case in

1868, when the island of St. Thomas was visited; and at the time of the earthquake of Jamaica, in 1692, the sea is said to have receded a full mile. No fully satisfactory explanation of this condition has yet been given. The rapidity of transmission of the earthquake wave is prodigious; after the disturbance on the west South American coast in 1868 (earthquake of Arica), the rolling swell made the transit to Honolulu, a distance of 5,580 nautical miles, in 12 hours and 37 minutes, or with an average velocity of 746 feet per second. This is nearly as rapid as the transmission of the actual earthquake pulsation through the solid rock. The Carolina earthquake of 1886 is assumed to have travelled, in one direction at least, at the exceptionally rapid rate of 16,000 feet (or three miles) per second; the Tokio earthquake of Oct. 25, 1881, 9,000 feet.

The number of impulses that belong to an earthquake varies. There are usually a first and a second shock; but oftentimes numbers of shocks, of greater and less magnitude, follow one another in rapid succession, to the extent of making an almost continuous earthquake of hours' or days' duration. At St. Thomas, in 1868, two hundred and eighty shocks were experienced in about as many hours; and in New Zealand, in 1848, it is claimed that for a period of a week or more the shocks were transmitted at the rate of a thousand per day. Again, the earthquake which visited Japan in the year 977 is said to have extended over a period of three hundred days.

CHAPTER XII.

CORALS AND CORAL ISLANDS.

THE coral cluster that gracefully adorns our mantel-tops is not usually viewed in the light of a geological specimen; it is an animal, and its history is a part of that of the organic chain. In reality, however, geology can claim the greater part of this history, since it is in its association with the rock-formations of the globe that the lowly organism teaches its most pregnant lesson. Few there are among the thousands who annually visit the lovely Bermuda Islands, or the less distant Bahamas, with their flecks and strips of gray sand, their wind-swept knolls and undulating hillocks, who realize the significance of the landscape that is before them; the wonderfully tinted waters, the peculiar vegetation of sub-tropical aspect, the pleasurable climate,— these are all elements that appeal directly to the æsthetic sense, but they reveal little of the history that is bound in with them.

The Aspects of a Coral Reef.—To understand properly what a coral island really is, and how it is manufactured, one has to visit that part of the sea immediately about it, wherein the coral animal is working and luxuriating—the coral reef. It is there that the material is being prepared for future rock-construction, there that a battle is constantly being waged

Plate 45.

1.

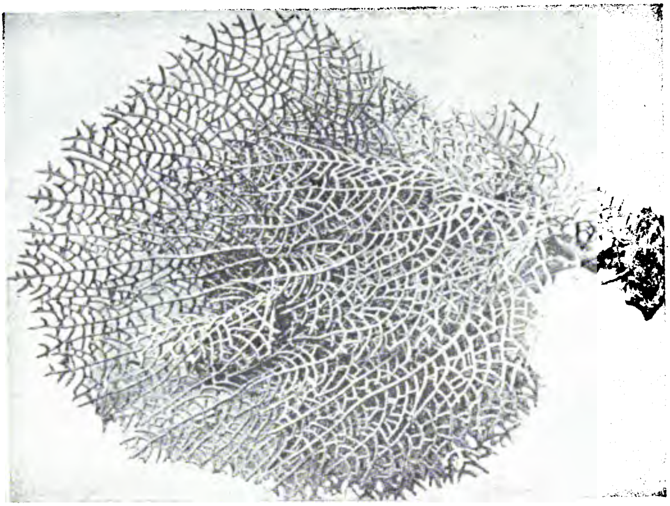
2.

CORALS AND CORAL ISLANDS.

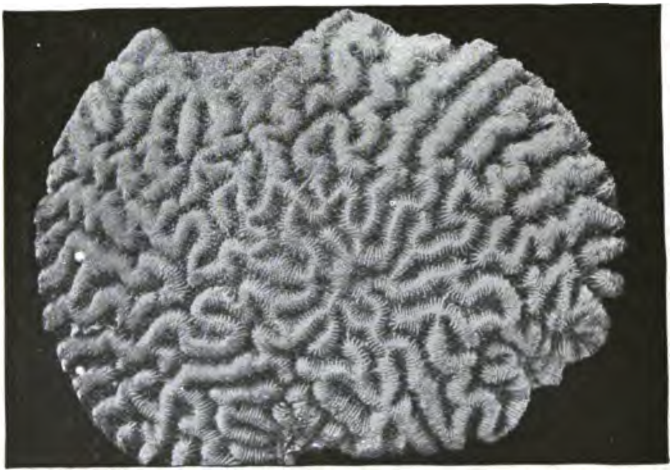
1. The æolian coral-sand rock of the Bermudas, showing wind-drift stratification.

2. A portion of the coral-reef known as the Great Barrier Reef of Australia, showing the closely matted and confused growth of the corals. The rounded masses are "brain-corals."

Plate 46.



1.



2.

CORALS AND CORAL ISLANDS.

1. A fan coral, *Rhipidogorgia*, from the Bermuda reefs.
2. A portion of a brain-coral, *Mæandrina*.

between the organic and the inorganic forces for supremacy and possession of the sea. My own first impressions of the growing reef were obtained at a lonely locality, removed about nine miles to the northward of the Bermuda Islands, and known as the North Rock. This North Rock is, in fact, an assemblage of three or four small rock-pinnacles, which in low water show themselves to be united by a connecting base, but in high water stand separate, each for itself. Standing on this connecting base, and looking over to the ocean side, one sees a wonderful assemblage of living animal forms, the greater number of which are clumps and heads of various kinds of coral, some small, others measuring several feet across; luxuriating near the surface of the water, and in their various colors and shades of orange, green, brown, and purple, they are spread out before the eye like the pattern of a mosaic pavement. Well in among these coral masses are a multitude of sponges, — black, yellow, and vermilion, — various coralloids (millepores), sea-fans, and squirts, all of them firmly attached like the corals themselves, while between them run about an army of crabs, of colors hardly less brilliant than those of their immediate surroundings. A variety of shells is invariably associated with the growing reef, and in the numerous holes and crevices the eye cannot fail to detect the spines or hard cases of a number of sea-urchins. This is, in a general way, the composite picture of a coral reef, a type of very nearly all of its class, but which carries with it no conception of the rapturous beauty of its construction. No flower-garden of the earth surpasses it in wealth of kaleidoscopic coloring; and it may justly be doubted if any approaches it, for the silvery texture of the overlying water adds a luminosity and brilliancy to the scene for which neither the calm atmosphere nor the warm sunshine can offer a substitute. To have seen the world without having visited a coral reef is to have seen a picture with the best of its coloring left out. (Plate 45, Fig. 2; Plates 46, 47.)

The Making of Coral Land. — All the active life of the coral is carried on within a few feet of the water's surface, for there is only a limited number of the reef-building species which thrive at a greater depth than 15 or 30 feet: some types live with a certain amount of luxuriance down to 80 or 100 feet, a few even at 300 or 400 feet; but by far the greater number are confined to the upper zone, where there is a strong penetration of sunlight. They, moreover, require a mild temperature, one that rarely descends below 68° or 60° F. This condition restricts the distribution of the reef-building corals to a nearly tropical or sub-tropical zone, and there are but few instances where there is a marked transgression beyond this zone (Bermudas; Quelpaert's Island, near Corea). Wherever the polyps build close to the surface, their habitations are attacked by the surf which they themselves create. The long white line of foam which meets the eye of the observer gazing off from any of the eminences of such an island group as the Bermudas, and which parts the blue waters of the outer world from the more nearly green within, is but the line of battle between the organic and the inorganic forces. Blocks of coral and coralline are detached and broken, their parts are rocked to and fro in the withering crest, and ultimately, when the fragments

Plate 47.

CORALS AND CORAL ISLANDS.

1. Rose coral (Isophyllia). 2. Branch of Oculina. 3. Millepore (right-hand figure).

have been sufficiently punished by the sea, they are handed over for further chastisement to the action of the wind. In this way the particles are ground finer and finer, true sand is formed, and dunes begin to rear their heads above the ocean level. Travelling in the line of the wind, the dunes pass onward, climb over one another's backs, and comb the gently flowing crests; from pygmy hillocks they rise into well-fashioned knolls, and ultimately stand as eminences, such as are to-day the Bermudas. No one who has watched the great tongues of moving sand stealthily encroaching over the hilltops of the interior, and burying everything, in the manner of the locusts of South Africa, beneath their mantle of destruction, can have failed to be impressed with the character and the magnitude of the work that is being accomplished. It is nothing but the music of the sea and wind, but there is enough of it to turn water into land.

This, then, is a coral island. It has its caves, lagoons, and separating watercourses, — its flat reaches of coral sand and shell, its hills and hummocks and sea-cliffs. The decaying rock has made soil, and over it, perhaps, has spread a vegetation of soft luxuriance, elsewhere scraggy and deficient in noble character. The wind-drift or æolian character of the rocks is everywhere apparent; along the roads, on the hillsides, and in the caves, we find the same rock made up of organic particles. The layers or seams, inclining now one way, now another, point to the different positions into which the sand has been fortuitously cast by the winds, patted down, and built up into a series of superimposed layers. Shells, both marine and terrestrial, have been caught in the drifts, for we find them imbedded in the rock, and scattered up to a height of 200 feet. (Plate 45, Fig. 1.)

The Kinds of Coral Islands. — The type of coral island that has here been described is that which is represented in the Bermudas, the Bahamas, and the Florida Keys. Briefly characterized, they are consolidated heaps, 50 to 260 feet high, of coral and coralline fragments or sand, which have been tossed up by the wind, and whose origin is the growing reef outside. Irregular bodies of water — lagoons or sounds — scatter themselves about the separated patches or islets, and in them, too, is a fairly luxuriant coral growth. As distinguished from this simple type — although in some instances only a modification of it — are the forms known as *fringing reefs*, where the coral structures hug pretty closely a more or less extended coastline; *barrier reefs*, where these structures follow the trend of a coast, but are yet separated from it by a narrow, oftentimes very profound, body of water. The Great Australian Barrier Reef is usually described as a nearly continuous reef structure about a thousand miles in length, with a separating width of water ranging to fifty miles, and with a depth of 350 feet. Other forms are *atolls*, or ring islands, where the construction is in the form of a narrow ring or collar of living and dead coral, encircling a central lagoon, 50 to 300 feet in depth. This lagoon, like the inner waters of barrier reefs, is kept in communication with the outer body of the ocean by means of one or more channels breaking through the coral wall. In all these various forms of coral structure the same fundamental principles of development govern the making — corals growing in shallow water, breakage through the action of the waves and surf, and the heaping up and distributing of the materials derived from destruction ("coral sand") through wind-action. There are, however, certain phases in the life-history of coral islands which have a special significance of their own, and a bearing upon broad questions in geology which gives to them a particular importance. We shall turn to an examination of some of these.

Occurrence in Deep Water; Formation of Reefs.— Nothing strikes the investigator more strange than the fact that, while the reef-building corals themselves live only in shallow water, their structures seemingly rear themselves up from the profoundest depths of the ocean. Thus, within a few hundred yards off the bounding reefs of the Bermudas, the lead drops a thousand feet and more, and at a distance of some seven miles, it drops to 12,000 feet. Were the full height of the island-group visible from this side, it would present the appearance of a huge rock buttress, the like of which could hardly be matched among the mountains of the dry land. Similar sudden plunges associate themselves with coral islets of the Pacific basin; and in a few instances it is claimed—although the fact perhaps requires further confirmation—that the descent for considerable distances is well-nigh vertical, or absolutely so. It would thus appear that the coral-made rock is one of very considerable thickness, of far greater development than would be permitted by the shallow zone in which the polyps live and build. Hence, we naturally ask ourselves: Under what special conditions can this apparently thick rock form?

To the genius of the late Mr. Darwin we owe the explanation, combated in some quarters of late, but which has most generally been received by geologists. He assumed that, in all regions where the corals built up from deep water, we had positive evidence of subsidence in the trough of the sea. The sinking of the fundament carried with it the already made rock, and allowed new material to be built up or accumulated with equal rapidity on the descending surface. In this way the working corals were steadily being submerged beneath the proper zone of their existence; their activity ceased, and the living rock became converted into "dead" material; but the more favored portion of the community worked busily onward on the top, and filled up the space that was continuously open to them in the shallows of sixty to one hundred feet depth. It will readily be seen that through this process of sinking at the bottom and growing on the top, an almost endless thickness of rock might in course of time be formed.

Thickness of Coral-Made Rock; Subsidences. — It is still an open question with many geologists whether or not coral rock has anywhere the very great thickness that has been assumed for it in many cases; if it has not, there is no need to invoke the assistance of subsidence to account for the phenomena as they present themselves. Some geologists have argued, and still argue, that the coral islets — like those of the Pacific basin — which rise with such sudden steepness from the deep hollow of the ocean, are merely thin "cappings" perched upon the crater-heads of submerged volcanoes; others maintain that they are only the final deposit of organic material which has accumulated on banks that have been built up in part mechanically, and in part by organic agencies other than those of coralline life — that is, by animal types whose activity is not limited to the shallow zone of sixty or one hundred feet. To both of these suppositions the only answer that can be given is that they remain in the nature of hypotheses; no such array of submerged volcanic peaks as would be found necessary to account for the numerous coral islands and islets that dot the Pacific has been shown to exist — in fact, it is almost certain that they do not exist; nor has it been shown that any extensive banks, except possibly near the shore in the line of the continental sediment, have ever been reared up in the manner that has been assumed, through thousands of feet of oceanic water. The Florida reefs and the Bahamas may in part lie on such mechanically and organically constructed platforms, but their continental position is special to themselves, and hardly permits a bearing on the general question. On the other hand, it is positively known that, in some instances at least, the solid coral rock has a thickness of three hundred or four hundred feet, and therefore much exceeds the development that would be permitted were there no subsidence; and further, it is equally certain, and proved by evidence of a very different kind, that subsidences have taken, and are still taking, place in regions where many of the coral reefs and islands are situated.

The Atoll Lagoon. — One of the most perplexing features of coral islands is the deep central depression, the lagoon of the atoll. We have seen that it has a depth ranging anywhere from a few feet to several hundred feet; therefore it extends far below the zone of the living animal. By Mr. Darwin, and his followers of the "subsidence" school, it was held to represent the position of a piece of land-area around which the coral animals had primarily established themselves, and which in course of time disappeared by sinkage. When yet at the water-surface, with the corals working around it, it was separated from the forming reef by a circle of water, which was kept barren of coral habitations through the condition that the reef-building coral does not thrive in muddy water, or in water that receives the down-wash off decaying land-masses. As subsidence proceeded, the belt of separating water became progressively larger, until finally, with the full disappearance of the land, it occupied the entire space included between the outside ring of coral. Thus was brought about the crateral hollow with its occupying waters. By some geologists it has been assumed that the hollow may have been occasioned by chemical dissolution of the lime; but it is certain that whatever amount is actually removed in this way, and there may be much of it, it is more than compensated for by the *débris* that accumulates within the basin itself as the result of rock-wear and breakages.

Elevated Reefs. — In many oceanic islands there is direct evidence to the fact that, instead of subsidence having taken place, elevation has been the order of movement, at least a late phase of it. We find coral reefs that are to-day high and dry, and yet we know that when they were being constructed they were in the water. Such raised-reef structures border a considerable extent of the island of Cuba, and are likewise found in Jamaica, in the Solomon Islands of the Pacific, etc. The fact of their being elevated has little or no bearing upon the general question of coral constructions; since, even if we have to admit prodigious subsidence to explain the seemingly anomalous position of the almost innumerable coral islands of the Pacific Ocean, there is nothing to preclude the possibility, or even easy probability, of an elevatory movement having followed that of subsidence. Nor are any geological facts opposed to the notion that movements of both elevation and depression may take place simultaneously, and side by side, in regions of moderate extent. Caution should here be emphasized as to the proper interpretation of the terms subsidence and elevation. It is by no means unlikely that what, in many cases, we assume to be "subsidence" of the land is merely a rise of the oceanic waters; and, conversely, the "rise" of the land may be only a falling-off of the oceanic waters. The records or marks that would be left by either one construction or the other would be fundamentally the same; and there are many reasons, as have already been stated, for assuming a decided instability in the level of the oceanic surface.

Distribution of Modern Reefs. — Nearly all the reefs of to-day are confined within the zone of twenty-five degrees north and south of the equator. They are most largely developed in the Indian Ocean and in the Australian and Polynesian Seas; the greater number of the archipelagic islands of the Pacific are in themselves of coral origin (like the Paumotu, Carolines, Gilbert, and Radack Islands), or volcanic, with surrounding areas of reefs (Tahiti, Samoa, Feejee, Hawaii). The larger Sunda Islands — Borneo, Celebes, Java, Sumatra — are almost destitute of coral structures, probably a result of the intensity of volcanic action in the region. Reefs are abundant in the Red Sea, and are found at intervals on the East African coast, extending opposite Port Natal to the 30th parallel of south latitude. In the Atlantic basin we have the Bermudas, Bahamas, Florida Keys, and the general West Indian region, together with scattered formations north and west of Yucatan, and in the off-shore of the Gulf of Mexico (Vera Cruz). Almost the entire west coast of America is free from these habitations.

Ancient Reefs. — There is plenty of evidence in the rocks to show that reef-structures of one kind or another were extensively developed throughout nearly all the periods of geological time, and in many of them on a seemingly much more gigantic scale than at the present time. Furthermore, their development was not restricted to the comparatively narrow geographical zone to which the energies of coral life are to-day confined; but it extended far toward what is now the Arctic realm, and in some regions well within it. Ancient reef-structures have been noted in Russia and in Scandinavia far beyond the 60th parallel of latitude, some of the reef-building types of coral having left their impress in the rocks of Spitzbergen and Nova Zembla ; indeed, much the same forms were obtained by the British North Pole Expedition of 1875–1876 from a point on the American side beyond the 82d parallel of latitude. These facts make it certain that the thermal conditions of the northern waters were very different from what they now are; probably the temperature was very much higher, generally equable, and more like what we have to-day in the tropical and subtropical zones. Yet we are by no means certain that the climate was in fact like that of our southern regions, as the types of the ancient corals are largely different from that now existing; and the conditions governing their existence may have varied essentially from those that regulate the coral life of the modern seas.

CHAPTER XIII.

FOSSILS AND THEIR TEACHINGS.

What a Fossil is. — There are not very many things more difficult to define than fossils. Ordinarily, they are assumed to be organisms, or remains of organisms, which have for some time been buried in rock, mud, or clay, and become "petrified," i.e., turned into stone. This definition probably explains a large number of cases of fossilization, but by no means all; for in very many instances what geologists term fossils have in no way become truly petrified. Skeletons remain as distinctly bony as they ever were, without perhaps material change of any kind having taken place within them; again, any number of "fossil" shells are in no way different in character or structure from their allies or representatives living to-day. In the broadest definition, it may be said that everything is fossil that leaves an impression in the materials of a clearly defined rock, sand, or mud formation, provided this formation is not merely one of our own immediate time. Hence, fossils can be millions of years old, or have existed only a few hundred years, or even less; the more recent ones are frequently termed sub-fossils. Again, not only are animals and plants, and their impressions (footprints, etc.), fossils, but many inanimate objects or their marks are also classed as such; thus we

Plate 52.

FOSSILS.

A block of rock crowded with Ammonites; a piece of fossilized wood shows in the left. From the Jurassic deposits of England.

speak of "fossil raindrops," "fossil ripple-marks," "fossil sun-cracks," and even of "fossil glaciers." In the following pages, the discussion of fossil remains will be restricted to the belongings of the organic world (animals and plants). (Plates 5, 6.)

Manner of Occurrence of Fossils.—It stands to reason that, generally, the older the fossil, the more does it depart in texture, form, and color from the original of which it constitutes the remains. Sometimes the body or shell structure has been completely removed, and in its place we find stone; at other times, with shells, for example, these parts are not retained at all, and we have as fossils only the impressions made by the outside of the shell, or the filling in of the cavity of the shell itself,—"impressions," "moulds," and "casts." It is not often that the soft parts of an animal are preserved, either by substitution or otherwise, as decomposition and decay remove them too rapidly to permit of preservation; still, a few such instances are known, as, for example, the mammoths of the north Siberian ice-plains, the skin and muscle (strictly petrified) of certain ancient reptiles, and the stone-flesh of some shellfish. The so-called stone-men of sensational museums have nothing in common with this, and represent merely hardened tissues due to a special development of adipocere. Fossil man exists only as skeleton, and through his belongings in the form of crude implements, "kitchen middens," "charcoal heaps," etc.

There are a number of instances where the color-markings on shells have been retained through an astonishingly long period, believed by many to be a million years or more. It is indeed difficult to realize such a condition; but the facts speak for themselves, and permit of no contradiction. The most delicate plant structures, as we find them in the coarser veinings of leaves, or in the hairy down of others, have been similarly preserved as impressions in the rock, and certainly through a score of millions of years. Even the delicate, one might say evanescent, impression of the jelly-fish has been preserved for much of this length of time. Naturally, for every specimen or impression that has been retained, there are thousands, doubtless tens of thousands, which have gone their way, and left no mark of their existence to instruct or puzzle the geologist.

Progression in Structure. — Fossils of one kind or another, and of one form or another, are found in all rock-formations down to the fundamental gneiss and schist — consequently, down to what some geologists (probably more wrongly than rightly) have considered to be the foundation-stone of the earth's crust. Not that fossils are necessarily to be found in every rock-specimen that is taken up, or even in every mile of rock-surface, inasmuch as their traces may have been locally obliterated; but somewhere or other, whether it be in England, or Germany, or China, or the north of Pennsylvania, or Alabama, they do occur in the deposits of all ages down to the schist or gneiss, and there are excellent grounds for believing (although no positive proof of this supposed fact has yet been brought to light) that life extended almost immeasurably beyond the time which marks the appearance of the first trace of organism.

The most significant fact that is taught us by the millions of fossil forms that have been preserved is, that there has been a steady and progressive advance in the general type of organization from the oldest to the newest periods; that more highly developed or more complicated forms have successively replaced forms of simpler construction; and that this advance is still continuing to-day. In the oldest rocks, for example, no trace of backboned animals has yet been detected; when such do appear for the first time, they show themselves in their lowest types, the fishes; these are succeeded later by the amphibians (frogs, newts, salamanders), and these again by the reptiles. And if we take the fishes by themselves, we find that they, too, begin with their lower, if not absolutely the lowest, types, and progressively develop their higher ones. This history is repeated in the cases of the reptiles and quadrupeds — in fact, with every class of animals that is known to us. Naturalists are to-day well agreed among themselves that all animal and vegetable forms are derivatives from forms that preceded them; that however varied and manifold the types, these types, in hundreds of thousands, have been brought about by slow processes of modification, acting through ages of time, of a limited number of initial organisms. This is the substance of the "doctrine of evolution," the doctrine which sees in the origin of species not special creative acts, but merely the effects of time and surroundings as producing new and distinct forms. Hence it is, that, in following the geological record, we speak of progressive evolution, the evolving of higher or more complicated types of organisms from those simpler and more general in structure.

The Time-Standard of Geological History.—The law of progressive development appears to have been largely the same for equal periods of time all over the earth's surface; identical or closely related types, if they appear at all, appeared in much the same time, perhaps varying in a few thousand years, at all points of the globe. This fact has permitted geologists to mark off distinct eras or periods in the life-history of the planet, each of them determined by certain characteristic animal or vegetable forms, which either do not appear before or after such period, or else are by numbers so distinctive of it as to typify it clearly.—Thus, we speak of an age of trilobites, of fishes, of reptiles, etc., meaning that, at the times so designated, such and such animals were especially abundant, or, at least, were abundant in comparison with other forms. Again, major divisions of time have been further divided into minor ones, to which also special features are given by their respective faunas and floras. The rocks that belong to definitely marked periods of time are naturally designated by the general name of the time-period; for example, the rocks of the coal or Carboniferous period are known under the comprehensive name of the Carboniferous formation; and so the rocks of the chalk or Cretaceous period constitute the Cretaceous rocks, deposits, strata, or formation.

The following table represents pretty nearly the general view of geologists as regards the main divisions of time and formations; in it are shown the more distinctive animal types that characterize the different eras, and the (approximately) greatest thickness of rock that was formed in each interval of time:—

	Epochs and Formations.	*Faunal Characters.*
Cainozoic or Tertiary.	POST-PLIOCENE. Glacial Period.	Man (not improbably earlier). Mammalia principally of living species. Extinction of Mammoth and Mastodon. Mollusca almost exclusively recent.
	PLIOCENE. 3,000 ft.	Mammalia principally of recent genera — living species (hippopotamus) rare. Introduction of the sheep, goat, ox, bear, camel, macaque. Mollusca very modern.
	MIOCENE. 5,000 ft. OLIGOCENE. 3,000 ft.	Mammalia principally of living families; extinct genera (Mastodon, sabre-tooth Cats) numerous; species all extinct. Introduction of the hedgehog, mole, porcupine, beaver, squirrel, rabbit, tapir, rhinoceros, hippopotamus, hog, deer, giraffe, elephant, cat, dog, hyena — not, however, of living species. Mollusca largely of recent species.
	EOCENE. 10,000 ft.	Mammalia with numerous extinct families and orders; all the genera (with two or three possible exceptions — bat, opossum) and species extinct. Modern type Shell-Fish.
	Laramie. 5,000 ft.	Passage Beds between Cretaceous and Eocene.
Mesozoic or Secondary.	CRETACEOUS. 12,000 ft. Chalk.	Dinosaurian (bird-like) Reptiles; Pterodactyls (flying Reptiles); toothed Birds; earliest Snake; bony Fishes very abundant; Crocodiles; Turtles; Ammonites (with almost final extinction); Deciduous Trees.
	JURASSIC. 6,000 ft. Oolite. Lias.	Earliest Birds; Archæopteryx; giant Reptiles (Ichthyosaurs, Dinosaurs, Pterodactyls); earliest bony Fishes; Ammonites; Clam- and Snail-Shells very abundant; decline of Brachiopods; Butterfly.
	TRIAS. 25,000 (?) ft. New Red Sandstone.	First Mammalian (Marsupial?); 2-gilled Cephalopods (Cuttle-Fishes, Belemnites); reptilian Foot-Prints; Bird Foot-Prints?
Paleozoic or Primary.	PERMIAN. 5,000 ft.	Earliest true Reptiles.
	CARBONIFEROUS. 26,000 ft. Coal.	Earliest Amphibian (Labyrinthodont); extinction of Trilobites; first Cray-fish; Beetles; Cockroaches; Centipedes; Spiders. Luxuriant land Vegetation.
	DEVONIAN. 18,000 ft. Old Red Sandstone.	Cartilaginous and Ganoid Fishes; earliest land (snail) and freshwater Shells; Shell-Fish abundant; decline of Trilobites; May-flies; Centipedes; Crab. Land Vegetation.
	SILURIAN. 33,000 ft.	Earliest Fish; the first Air-Breathers (Insects, Scorpions); Brachiopods and 4-gilled Cephalopods (Nautiloids) very abundant; Trilobites: Corals; Graptolites.
	CAMBRIAN. 25,000 ft.	Trilobites; Brachiopod Mollusks; Corals (rare).
Azoic.	ARCHÆAN. 35,000 ft. Huronian. Laurentian.	No undoubted traces of fossils.
	PRIMEVAL.	Non-sedimentary.

The Variation and Extinction of Animal Forms. — Just what it is that causes animal forms to vary and ultimately to develop into new types or forms wholly unlike themselves, is not always apparent; but probably in most cases the variation, apart from an inherent physiological tendency of the organism to vary somewhat in its form, is brought about through a number of distinct causes. Among these may be enumerated changes in the character of the food-supply, the matter of climate, mechanical impacts resulting from accommodation to immediate environments, special necessities of locomotion and movement, and so forth. Adaptation, or fitting to all these requirements, may bring about success in the "struggle for existence," a condition that is rendered more or less permanent by the weeding out or extermination of such forms, or groups of forms, as have not been able to accommodate themselves in habit or otherwise to the necessities of their ever-changing surroundings. This process of *natural selection* is largely the determining element which brings about *evolution.*

It is commonly believed that the process of modification is an exceedingly slow one, and probably in most cases this is so. Hundreds or thousands of years may be required to impress newly acquired characters in such a way as to render them (for a time) permanent, and thereby to create new species. Yet it is by no means certain that some new types were not evolved in a comparatively short period, by a sort of saltus or jump; the problem is such that it does not permit of easy solution, although it is certain that within the period of man's own history or observation, — or through a space of time of from four thousand to five thousand years, — there have been few changes of magnitude in either the animal or the vegetable world, so far as the making of new types is concerned. The causes that bring about extinction are necessarily closely bound in with those that relate to the appearance of species; and they, too, are not easily determinable for particular cases. Thus, it is not made clear why the horse on the American continent should have become extinct long before the advent of the Europeans, when its modern successor, so absolutely like the ancient animal whose fossilized bones are scattered through various rock deposits, finds in the same region a seemingly congenial home. Certain conditions doubtless existed which were destructive to equine development at the time, or at least not favorable to it.

It seems to be a well-established fact that few forms of life, or the groups which they represent, after they once disappeared from existence, — or became "extinct," as geologists say, — ever again reappeared as constituents of a new fauna or flora. Hence, disappearances (as well as appearances) are landmarks in the fixing of geological chronology; by reading much the same history in all parts of the globe we are able to locate definitely the "horizons" or times which are made typical by the presence or absence of certain animal or vegetable types. Thus we know, referring back to the table on page 155, that no trilobites are found in deposits newer than the Carboniferous; any rock, therefore, that contains the remains of these animals, belongs to a period that is either Carboniferous, or of still older date. Again, a special genus of trilobites, known as

Paradoxides, has never yet been found in formations other than the Cambrian; hence, it is typical of the rocks of that period, and eminently serves to characterize them. Paradoxides is a "leading" or "type fossil," inasmuch as it serves by itself to distinguish a rock-formation. Almost every species of fossil has a definite position in the geological scale, and would by itself serve to locate a formation; but oftentimes the determination of species, owing to insufficiency of knowledge or the obliteration of characters, is a most difficult task, and then recourse is had to the aspect of the entire group of fossils which a given rock-mass contains. This generally gives the age or position without difficulty.

Kinds of Fossils; Marine, Terrestrial, and Fresh-Water. — Fossils are generally divided into three classes, — land, fresh-water, and marine, — being the remains of animal forms which lived respectively on the land-surface, in the streams and lakes of land-areas, and in the waters of the ocean. It is manifestly of the first importance to ascertain to which of these classes any given association belongs; as this will determine the kind of formation of which it constitutes a part — whether the formation is of terrestrial origin, a lake or river deposit, or the sediment of the ocean. Only after knowing this are the physiographical conditions surrounding a formation made clear to us. Under the name of "brackish-water fossils" are included those forms which inhabited a mixture of salt and fresh waters; such brackish waters are found in the estuaries or lower courses of all large streams that discharge directly into the sea. Many interior waters have become brackish or salty through over-accumulation of salt in their basins; an accumulation that may have been brought about by the disappearance of a natural outlet, or by unusually rapid desiccation, or by a combination of both conditions. The Great Salt Lake of Utah is an example of a fresh-water lake turned into a salty one, with an accommodation of its very limited fauna to brackish water conditions. On the other hand, it is equally certain that from what were at one time salt or brackish interior seas, fresh waters have been developed, and with them have originated certain types of fresh-water faunas. The possibilities of such conditions must always be present in the mind of the geologist when making his explorations.

The Origin of the Different Kinds of Faunas. — The oldest rock formations contain the remains of only such animals as by a combination of their characters are thought to have inhabited the sea. This circumstance has led to the very just conclusion that the animals first to come into existence were of an oceanic type. Fresh-water and land animals followed these considerably later. Many interesting suggestions have been made with regard to these later-appearing faunas, the method of their origin, etc., without perhaps yielding definite or positive clews concerning their relationship with the forms that inhabit the sea. Yet there are good reasons for assuming that the faunas of fresh waters are merely modifications or transformations of oceanic types, becoming such through gradual accommodation to new conditions of habitat — a change of location from the oceanic waters to those of the inflowing streams. Less secure is the ground on which one seeks to explain the origin of the dry-land fauna, as possibly a direct transformation from both the fresh-water and the oceanic faunas.

SUCCESSION OF LIFE.

Faunas of the Early Periods (Paleozoic). — In the oldest of what are generally considered to be sedimentary rocks, the **Archæan,** no unequivocal evidences of organic life have yet been found, although, doubtless, both animal and vegetable organisms had already come into existence at that early period. The life of the succeeding **Cambrian** period was, both numerically and in the variety of forms, a rich one; but the types represented appear to have belonged exclusively to the Invertebrata, or to animals wanting a vertebral column. The shellfish (Mollusca) and crustaceans (Trilobita) were preëminently abundant. In the period following, the **Silurian,** the influence of the Mollusca was still paramount, — hence the period is frequently designated the "age of mollusks;" but we have here, in addition, the first unequivocal evidences, in the shape of fish-spines, teeth, and armor-plates, of the existence of the higher backboned animals. Here, too, belong the earliest inhabitants of the land whose remains have come down to us, — scorpions, hemipters, and possibly cockroaches, true air-breathers of the modern type. The coral animal, whose presence in the Cambrian deposits had yet hardly been detected, seems to have found an unusually congenial home in the seas of this period. The **Devonian** was preëminently the period or "age of fishes," a class represented by the two familiar types of sharks and dog-fishes (cartilaginous fishes), and the nearly related ganoids, the last comprising forms like the modern sturgeon and alligator-gar, in which the body was protected by an armor of enamel plate or scales. The more highly constituted osseous or bony fishes had not yet been evolved. In the rocks of this period we find the earliest traces of animals that inhabited fresh water (fresh-water mussel), and the first of the air-breathing mollusks, a land snail. A promising terrestrial vegetation had gradually been unfolding, which in the succeeding **Carboniferous** age attained to almost unparalleled luxuriance. The vast deposits of coal, which have so long administered to the wants of man, bear ample testimony to this enormous development. For the first time we here meet with animal forms of a grade of organization higher than the fishes, — giant animals of the salamander type, and known as labyrinthodonts, sporting in the existing carbonaceous marshes, inhaling an atmosphere possibly surcharged with carbon, and giving forth to the solitudes not improbably the earliest organic sounds whose audibility was above that of the hum of insects. Hitherto, so far as the facts in the case have been revealed by geology, a general silence had pervaded the organic universe; the land, as well as the water, was tenanted by organisms to whom the production of sound was a stranger, and whose conception of the same, if such conception actually existed, must have been principally dependent upon the interaction of the inert mechanical forces alone. The **Permian** period brings forth the earliest true reptilian forms, — forms which in several points of structure foreshadowed the quadrupeds, and which not unlikely were ancestral to them; and we therein note a step in advance.

Faunas of the Middle Periods (Mesozoic).—It is not until the succeeding, or Triassic, period that we meet with the first of that series of animals, the Mammalia, whose special development constitutes the most marked feature of the organic life of the present day. Lowly forms, most nearly related to the marsupials, possibly usher in the class of the most highly organized of all animals. With this period a distinctively new era dawns upon the horizon. The familiar types of the preceding periods, if they have not already completely died out, now rapidly decline; new forms take their place, and a more modern aspect is gradually introduced. The mollusks are no longer for the most part brachiopods, but of the type of the snail and the clam; the old-time cuttle-fishes of the four-gilled order (represented in our day by the nautilus), although still flourishing, find their ultimate successors in the more highly organized two-gilled squid-like forms; the horseshoe and ordinary crabs, and their allies, have usurped the place of the trilobite among crustaceans; while among the lower orders, such as the sea-urchins and polyps, we find the true urchins taking the place of the more primitive stone-lily (crinoid), and the star-coral that of the tabulate and cup-coral types. Progressive development is everywhere manifest; we proceed from low to high, from the more generalized to the more specialized. The distinction in the faunal aspect separating the Triassic from the Permian period is more marked than that separating any other two consecutive periods since the Cambrian; we recognize here a great *break*, a seemingly new impetus having been given to the peopling of the earth. Such a break likewise separates the Cambrian and the Archæan periods. The **Jurassic** deposits yield the earliest unequivocal traces of a feathered creation, although seemingly some of the fossil foot-tracks of an earlier period belong to birds; reptilian in many of its characters, ornithic in others, the first of the feathered tribe (Archæopteryx) with which we are acquainted is a reptile as well as a bird. Its contemporaries numbered many of the most bizarre forms whose records have been left to us, — reptiles of the air, sea, and land, whose ponderous proportions are in many cases only matched by the whale, and whose avian affinities prove them to have been the ancestral stock whence some of our modern birds have been derived. The monsters of this golden "age of reptiles" were largely continued into the succeeding **Cretaceous** period, when, however, they gradually succumbed, and ultimately completely passed away. Their successors are the turtles, crocodiles, lizards, and serpents of the present day. This period is likewise marked by the advent, in considerable numbers, of the osseous fishes, the type of fish-structure which dominates the modern seas.

Faunas of the Newer Periods (Cainozoic). — Passing from the Cretaceous to the **Tertiary** period, we note the most marked of the numerous organic changes that present themselves in the geological system. As if with one jump, the shadows of existing life are called upon the scene; modern type-structures everywhere prevail, even though generic or specific identity be a matter of later times. We recognize in the Tertiary fauna the type of the existing mammal, bird, reptile, amphibian, and fish; the shells are essentially of the same character as those of our seas, and many of the forms are even specifically identical. And the same may be said of the starfishes, sea-urchins, and polyps, down to the lowest order of animals known. Correlatively with the development of the modern fauna, we remark the disappearance of those singular forms which served to distinguish the preceding periods, — the salamandroids of the Carboniferous and Triassic periods, the Jurassic and Cretaceous bird-like reptiles, and the toothed birds of the Cretaceous period. Finally, in the later Tertiary we are dealing with a faunal assemblage practically identical with that of the present day. Here man first steps in, ruler of the universe.

The periods of formation that we have been considering have been subdivided by geologists into minor periods or formations, depending upon certain special relationships or differences; but these need not concern us here. They have also, and for similar reasons, been united into more comprehensive groups, defined by the big breaks that have already been indicated; but these likewise have no special interest, except for the purposes of classification.

CHAPTER XIV.

THE ORGANIZATION OF SOME OF THE LESS-KNOWN GROUPS OF FOSSILS.

Foraminifera. — The animals of this group have been described in the chapter dealing with Chalk and the Atlantic Ooze (pp. 27, 28). As fossils, they occur in microscopic forms and of such size as to be easily recognizable by the eye; indeed, some of the elongated types, as *Nodosaria*, *Dentalina*, etc., measure at times a third of an inch in length or even more. Frequently the shell of the animal has been completely removed, and we have then only the filling, or the "casts," of the different chambers preserved. This is largely the case with the Foraminifera of the "green marls" of the Atlantic border of the United States, where we find rounded pellets of the mineral glauconite representing the spaces of the shells which were at one time occupied by the living part of the animal. The Foraminifera extend back in geological time almost to the earliest period, and they show a remarkable persistence in their general forms. Some of the oldest types are barely distinguishable from forms living at the present day. Chalk and some other kinds of limestones are made up in large part of the shells of these animals.

Corals, of one kind or another, are found in almost every geological formation; but the older types are quite distinct in structure from those of the modern seas and of the more recent deposits. And possibly, when we speak of ancient reef-structures, we are not permitted to conclude that the conditions governing their formation were the same as those which govern reef-making at the present time, either as to temperature or depth of water. The older corals, from the Cambrian period to the Carboniferous inclusive, are of the two types commonly recognized as the *tabulate* and the *cup corals*. In both of these types the partitions, or septa, which in the recent coral radiate off from a central elevation or columella, and make the perfect star that is so well known to all who have looked carefully at a complete specimen, hang closely to the sides of the individual cups, and only unite with one another at the bottoms of the cups. Again, in both the tabulate and cup types, the coralla, or "calyces," are partitioned off by a number of distinct horizontal or wavy plates, which are the *tabulæ*. In the first of these groups we have compound assemblages of cups, or coralla, which are often united in the form of chains ("chain coral," *Halysites*), wasps' nests ("wasp-nest coral," *Michelinia*), honeycombs ("honeycomb coral," *Favosites*), or organ pipes ("organ-pipe coral," *Syringopora*). The cup corals are usually single, and can be easily recognized by their elongated or depressed cups (*Cyathophyllum*, *Heliophyllum*, *Zaphrentis*).

Trilobites. — No class of fossils is so eagerly sought after by the young geologist as the trilobites. Their singular appearance, so suggestive of animals of a much higher grade of organization, combined frequently with an excellent state of preservation, is what perhaps makes them specially attractive; at any rate, a trilobite hunt is always a selected feature in the study of paleontology. The animals of this class are all extinct, and have been so since the close of the Carboniferous epoch; hence, they are a distinctively ancient type. The name trilobite ("three-lobed" animal) is based upon the fact that the hard part, or shell, of the animal is in most cases divided into three distinct parts; an anterior part, or head-shield (which protected the stomach and mandibular parts placed beneath it), a tail-piece (*pygidium*), and a middle piece, or abdomen. In many of the forms the shell shows an additional lateral trilobation, i. e., a right-hand lobe, a middle lobe, and a left-hand lobe; but the name is not derived from this construction. On top of the head, or cephalic shield, we usually find a central eminence or swelling, known as the *glabella;* and it is immediately beneath this that it is assumed the stomach was placed. Two compound eyes, frequently showing well their many facets, and at times supported on long stalks, are generally found lying off the sides of the glabella. The abdominal portion, and less often the tail-piece of the animal, are divided into a number of distinct segments; and these were sometimes so freely movable upon themselves that the animal was able to roll itself up into a ball (*Phacops, Calymene*), in the manner of the wood-louse and armadillo. Recent discoveries have shown conclusively that the living animal was provided with filamentous and gill-bearing appendages and swimmerets, much like some of the modern shrimp-like animals, and the limulus or horseshoe-crab. Seemingly the trilobites were more nearly related to the latter than to any other animal that to-day inhabits the sea. They were true crustaceans, and all of them marine in habit, with a leaning to shallow and muddy waters. They were of the most diverse sizes, ranging from forms (*Agnostus*) that were no larger than the head of a pin, to others that measured a foot or even nearly two feet in length (*Paradoxides*, *Asaphus*); and it is singular that both the largest (or very nearly the largest) and the smallest forms occur in association, and in nearly the oldest of the rock formations. (Plate 53, Figs. 4, 4*a*; Plate 54.)

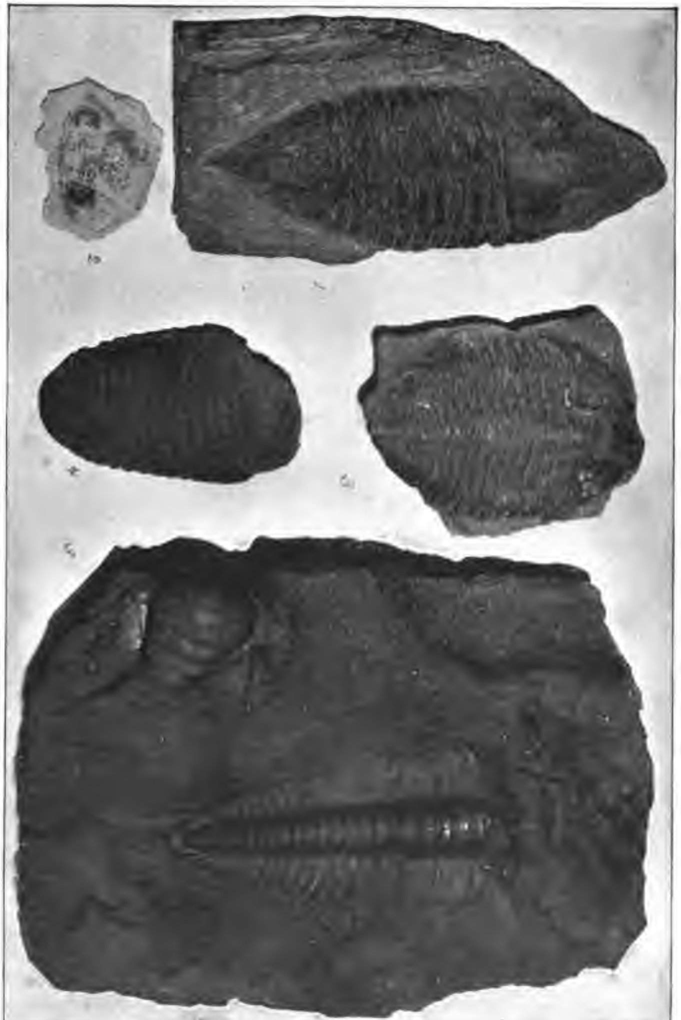
Crinoids or Stone-Lilies. — Next after the trilobites, perhaps the best known of the fossil forms are the crinoids, or stone-lilies. They are animals which belong near to the starfishes, of which, in fact, they have by some naturalists been constituted a sub-class. The relationship between the two groups is not immediately apparent. If you take a many-armed starfish, turn it with its mouth looking upward, and gently fold over the arms into a bunch, and then imagine it has a long stalk to support it, you will have, in all essential details, a crinoid; the fact is, there are one or two forms of starfish which have a short appendage to their backs, and this appendage is by many considered to be the remains of what we recognize in the crinoid stem. A crinoid, or stone-lily, in its completion consists of a stony body or calyx, supported on a long, many-jointed stem, which stem (either cylindrical or pentagonal in outline) was rooted to the sea-bottom during the life of the animal. Within the calyx were contained the soft parts of the animal, with a central mouth looking upwards; or, if the calyx hung over like the tulip-bell, then naturally the mouth looked

Plate 53.

FOSSILS.

1, 3. Crinoids, or "stone lilies." **1, 1a.** Pentremites. **2, 2a.** Crinoid-stem "buttons." **3.** Crinoid with stem attached. **5.** Glyptocrinus. **4.** Trilobite (Calymene). **4a.** The same rolled up.

Plate 54.



FOSSILS. — TRILOBITES.

1. Homalonotus (from the Devonian). 2. Head of Phacops, showing the two lentil-shaped eyes. 3. Phacops (Silurian). 4. Body of Homalonotus. 5. Paradoxides, with the head sheared off from the body (Cambrian).

downwards. From the border of the cup sprung five many-jointed arms, which subdivided at short intervals, and on their inner faces carried numerous delicate, also many-jointed, feather-like appendages (or pinnules), whose motion doubtless helped to bring a food-supply to the animal, and perhaps additionally served in the process of respiration. (Plate 53, Figs. 1, 2, 3, 5.)

The parts of the crinoids that are usually found are the segments of the jointed stem, the so-called "crinoid buttons." These are of various forms and sizes, ranging upwards to an inch in diameter; but they almost invariably show one character in common, the central hole or perforation. Through the continuous hole, from one end of the stem to the other, passed a ligament, or muscular string of some kind, which helped to keep the different parts together. Crinoid buttons and sections of stems are at times so abundant as virtually to build up a "crinoid rock" or reef, and this more particularly among the Carboniferous deposits. Stems have been found which measured three or even four feet in length, and others existed which were yet much larger. The group is an ancient one, which attained its maximum development in the period covered by the Silurian, Devonian, and Carboniferous formations; at the present time it appears to be verging on extinction, almost the only localities where its representatives occur in abundance being the Caribbean and West Indian Seas.

Brachiopods. — Under this name, and generally referred to the class of mollusks, although perhaps showing more actual affinity with certain kinds of worms, are grouped an association of shell-bearing animals which are of the first importance in the decipherment of rock-formations. They are, to the older and middle periods of geological history, what the ordinary shell-fish, the clams and snails, are to the more modern rocks, and as constituents of the world's existing fauna. The brachiopod shell was always a double one, i.e., consisted of two valves; but it differed from that of ordinary clams or bivalve shell-fish, in that the two valves were of unequal size, a larger and a smaller. The beak of the larger valve was usually perforated at its centre; and through this aperture, which was sometimes situated below the beak, passed an attaching muscular bundle or peduncle. Another feature distinguishing the brachiopod shell from that of the ordinary shell-fish is the right and left symmetry of each individual valve; a line drawn downward from the beak divides the shell into an equal right-hand and left-hand part. This, as we know, is not the case with the clam and its allies, where the beaks are usually placed considerably forward (less often backward, and still less frequently central). Of course, a few exceptions to both conditions could be cited from either class of organisms. In most brachiopods, there was contained within the soft body of the animal a limy arm-skeleton, or internal support, known as the "spiral" and "carriage-spring arrangement," against which were appressed the delicate and freely movable arm-gills, constructions which are not present with the true mollusks. The shell itself is generally of lime construction; but in exceptional forms it is of a horny texture, which has served in some instances to preserve it unchanged throughout nearly all geological time.

Plate 55.

FOSSILS. — TYPES OF BRACHIOPODS.

1, 1a, 1b. Terebratula. **2.** Terebratella. **3, 3a.** Rhynchonella. **4, 4a.** Atrypa. **5.** Athyris. **6.** Merista. **7.** Retzia. **8.** Strophomena. **9, 9a, 9b.** Spirifer. **10, 10a.** Leptæna. **11.** Productus. **12, 12a, 12b.** Orthis. **13.** Chonetes.

Plate 56.

FOSSILS.—TYPES OF CEPHALOPODS.

1. Belemnites (internal shell of a fossil cuttle-fish, squid, or calamary).
2-5. AMMONOIDS.—2. Scaphites. 3. Ancyloceras. 4. Crioceras. 5. Baculites.
6-7. NAUTILOIDS.—6. Nautilus. 7. Orthoceras.

The Brachiopoda are surpassingly abundant in nearly all the older formations; and it is, perhaps, not wrong to say that they culminated as early as the Silurian period. Very nearly the oldest fossil known to us, found at the base of the Cambrian series of rocks, is one so near to the modern lampshell or goose brachiopod, the *Lingula*, that for many years it was considered to be all but specifically identical; of late years some special characteristics have been found to distinguish it, and it is now known as *Lingulella.* Another very ancient type, and still living, although in restricted numbers in the modern seas, is *Discina.* The genera *Spirifer*, *Orthis*, and *Rhynchonella* are amongst the most abundant of the Silurian and Devonian fossils. An abundant form of the Jurassic, Cretaceous, and Tertiary deposits is *Terebratula.* The group has little importance at the present time, having been almost entirely superseded by the true mollusks — the snails and bivalves. (Plate 55.)

Ammonites and their Allies. — These are, broadly speaking, ancient cuttle-fishes, which inhabited shells of various forms and sizes, — some of them the largest of all known shells — and whose only near modern representative is the beautiful pearly nautilus. This animal, as is well known, inhabits a chambered shell, almost all of it being located in the anterior chamber, while the posterior series, with their partitioning "septa," appear to serve mainly as a helping float. Through the different septa, nearly in the centre of each, passed a tube or siphuncle, in which was located the attaching muscle of the animal; this siphuncle disappears with decay, and in its place we have merely the central perforations of the septa. All of the type of cuttle-fishes that conform within close limits to the nautilus are known as "nautiloids," but they differ from one another in the manner of the winding of the shell. Thus, in the Silurian *Gyroceras*, the shell winds up in an open, instead of a closed, coil; in *Lituites* it is partly coiled, while a portion, that which finally accommodates the body, was thrown off in a straight tangent to the initial coil; in the Cambrian *Cyrtoceras*, we have nearly a curved union of chambers, looking like an antelope's horn; and finally, in *Orthoceras*, which after the nautilus itself is the most abundant of the known forms, the shell is perfectly straight. Despite these variations, the characters which they have in common serve to unite them as nautiloids.

Closely related to the nautiloids, and in a measure running parallel with them in the diversity of their forms, are the "ammonoids," whose most distinctive type is the *Ammonites* ("Jupiter-Ammon Stone"). In this form, and equally so in its allies, the shell is much as in the nautiloids; but the septa, instead of being simple in construction as they are in the nautilus, are complicated by a series of remarkable infoldings, the extent of which can be seen by examining the lines of "suture" where the septa come to the outside of the shell. They give a peculiarly ornamental appearance to the surface, very different from anything that is to be found on the shell of the nautiloids. We speak of the septal marks, or sutures, as "foliated," instead of "undulated," as they are in Nautilus, Orthoceras, etc. Another difference separating the two groups is found in the position of the siphuncle, which in the ammonoids runs to one side (on the back, or dorsally) of the different chambers. All the ammonoids are extinct at the present day, and have been so since the beginning of the Tertiary period; nor do we know of any forms which preceded the Carboniferous period, except a limited number of types (*Goniatites*, *Clymenia*) which seemingly united them with the nautiloids. Not knowing the soft parts of the animal, naturalists have not been able positively to determine its relationships; and perhaps a broader difference separates it from the nautiloids than is generally admitted. Some authors have indeed gone so far as to assume that the ammonoid shell was internal, and not external, more like what we find in the modern *Spirula*, the pearly shells of which are so abundantly thrown up on portions of our Eastern coast. (Plate 52.)

The shell of the ammonoids shows the same variations in coiling, etc., that are found among the nautiloids. It is closely coiled in Ammonites, coiled in an open plane in *Crioceras*, partially coiled in *Ancyloceras*, doubly incoiled in *Scaphites*, merely curved in *Toxoceras*, coiled in an elevated spire in *Turrilites*, and finally it is perfectly straight in *Baculites*. Most of these departures appear toward the close of existence of the group (Jurassic, Cretaceous); and it is surprising as reversing the order of appearance among the nautiloids, where the less-coiled forms come first, and are then followed by the uncoiled and the straight shells. (Plate 56.)

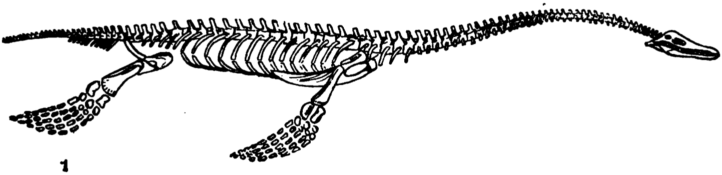
Belemnites. — Under this name geologists recognize a type of fossil which represents the modern squids or calamaries of the regular ten-armed tribe of cuttle-fishes, in which whatever represents the shell is internal, and not external. This shell, so-called, is familiar to many readers under the form of the horny "pen" of the loligo, and of the limy "cuttle-bone" which so often finds a place in the cage of canary birds. In the belemnites, or belemnoids, the correspondent of this shell was a cylindrical object, oftentimes having the appearance of a cigar (hence "fossil cigars"), with an expansion in front, and containing a small chambered cone in the upper part of its central cavity. It seems that to the top of this cone was fitted the base of the "ink-bag," the organ from which, as in the living squids, an inky fluid was projected at the will of the animal. Enough of the soft parts of the belemnite has been preserved clearly to establish the relationship of the animal, and to give it its proper position beside its modern ally. The belemnite shell, which is the only portion of the animal that is usually preserved in its fossil form, may measure several inches in length, and not infrequently it exceeds a foot. It occurs in particular abundance in the Jurassic and Cretaceous rocks, and seems to entirely disappear with the latter. A most interesting circumstance connected with the fossilization of these animals is the preservation of the solidified ink. This "fossil sepia," for that is what it really is, has under proper treatment been made to yield good writing and painting fluid — a preparation extending back hundreds of thousands, or even millions, of years. (Plate 56, Fig. 1.)

CHAPTER XV.

FOSSIL FISHES, BIRDS, REPTILES, AND QUADRUPEDS.

Fossil Fishes. — The earliest positive evidences that we have of the appearance of fishes are found in a few fragmental parts (teeth, spines, and plates) of the newer Silurian period. These, as well as those of the succeeding periods up to the Jurassic, belong almost exclusively to the group of cartilaginous fishes, like the shark, ray, etc., in which the backbone has not yet been completely converted into bone; and to a second group, — not distantly removed from these, — the members of which are commonly spoken of as *ganoids*. A common character of the latter is the armature of large or small enamel (or bony) plates, which formed an almost complete casing to the animal; hence, these fishes are frequently spoken of as "armored" and "bucklered" fishes, among which, as lingering modern representatives, are the sturgeon and the alligator-gar. The ganoids are so abundant in the rocks of the Devonian period that this time-measure is often styled the "age of fishes." Among the largely armored forms may be mentioned *Cephalaspis*, *Pteraspis*, *Pterichthys*, which have of their kind no existing representative; *Holoptychius* appears to have been nearly related to the sturgeon. The gigantic *Dinichthys* and *Titanichthys*, measuring perhaps twenty feet or more in length, and

Plate 58.



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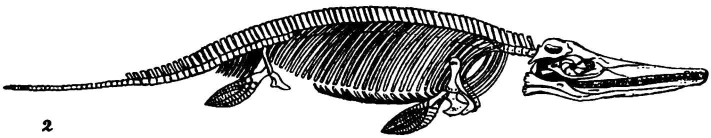

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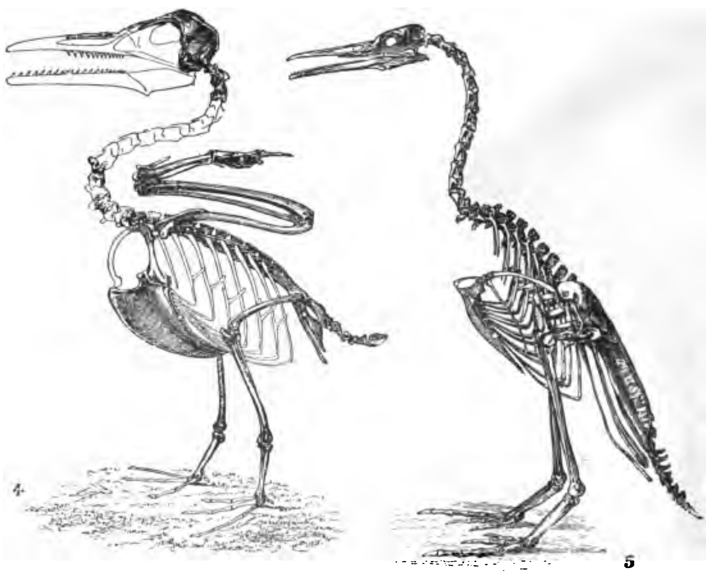


4 5

FOSSILS.

1. Plesiosaurus, a marine swimming reptile. 2. Ichthyosaurus, a somewhat related form; both of them are largely represented in the Jurassic rocks of Europe. 3. Clidastes, a sea-serpent of the Cretaceous period. 4, 5. Toothed birds (Odontornithes), from the Cretaceous rocks of America. 4, Ichthyornis. 5. Hesperornis.

rasaurus, *Triceratops* — were among the largest of all known animals, measuring from twenty to seventy (perhaps ninety) feet in length. They appear to have been mainly herbivorous in habit, and to have inhabited swampy or marshy tracts. A certain number of dinosaurs, like *Iguanodon* and *Hadrosaurus*, were erect in posture, or at least partially so, a condition in progression to which their greatly elongated hind appendages well fitted them; it is to such animals, doubtless, that many or most of the large three-toed impressions that are found in certain rock-deposits, and had for a long time been referred to birds, belong. None of the animals of this class appear to have survived into the Tertiary period. (Plates 58, 59.)

Pterodactyls. — These are large and small reptile-like animals, to an extent having the structure of birds, which were provided with a great tegumentary expansion, in the nature of a wing, uniting the anterior with the posterior limbs. The wing is mainly supported by a greatly elongated first finger of the hand, and in this respect differs entirely from the representative organ found in birds and bats. Both lower and upper mandibles were in some of the forms provided with crocodilian teeth — teeth implanted in distinct alveolar sockets. All the animals of this group are confined to the Jurassic and Cretaceous deposits; while some forms were no larger than a pigeon, others (*Pteranodon*) appear to have measured fully twenty feet in expanse of wings. (Plate 57, Fig. 2.)

Archæopteryx. — This singular organism, of which only two specimens showing any degree of perfection have been found, — one now in the British Museum, and the other in the Museum of Berlin,—is almost directly intermediate in structure between bird and reptile. The animal, which was of about the size of a crow, had a bird-like head (yet with distinct teeth near the extremities of the beak), bird-like limbs, true feathered wings, and a feathered tail. The arrangement of the feathers on the tail, running as they do in opposite series on the two sides of the axis, instead of radiating off fan-like from an abbreviated extremity, is wholly unlike what is to be found in any true bird, while the long caudal column is of a clearly reptilian character. The body portion of the animal, singularly enough, appears to have been entirely, or almost entirely, naked, thereby again differing from birds. The two specimens of Archæopteryx referred to, and two additional feathers—all that has thus far been found of the animal—are from the Solenhofen (Bavarian) quarries of lithographic stone, of Jurassic age. (Plate 57, Fig. 1.)

Birds.—Remains of birds are not abundant, a circumstance which, doubtless, stands in association with their aërial method of life. The oldest fragmental parts belong to the Jurassic rocks; but almost certainly some of the smaller three-toed impressions which are found in more or less abundance in the sandstones of the Trias are the foot-marks of these animals. It is mainly in the rocks of the Tertiary period that their fossils acquire any significance, and even there they are not of sufficient abundance or importance to constitute them sign-posts in the procession of life. A number of remarkable giant birds (*Dinornis*, *Notornis*), having some of the characters of the modern struthians (ostriches and their allies), but much more powerful in their frame, are known from comparatively recent deposits of New Zealand, and some of them appear to have become extinct so recently as to be hardly beyond the memory of man. Of about the same period is the *Æpyornis* of Madagascar.

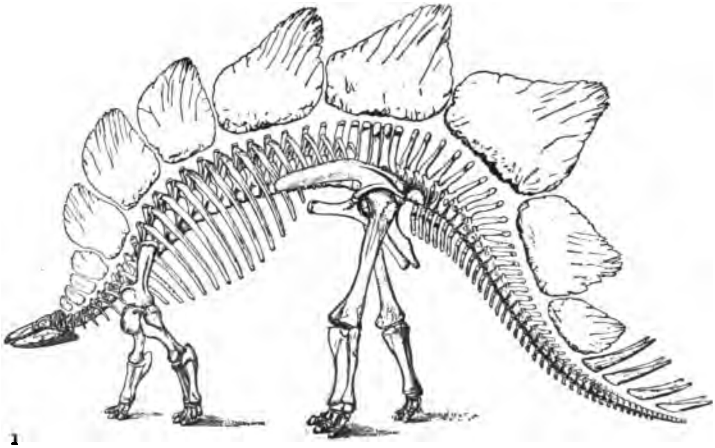
In the Cretaceous of the Western United States are found the remains of a very remarkable group of birds, whose whole structure was absolutely bird-like, except in the one character of having a full series of socket-teeth implanted in both the lower and upper mandibles. These constitute the *Odontornithes*, or "toothed birds," the best known representatives of which are *Hesperornis regalis* and *Ichthyornis dispar*. (Plate 58, Figs. 4, 5.)

Mammalia (Quadrupeds). — The rocks of the Tertiary period are preëminently characterized by the remains in abundance of the highest of the animal forms, the Mammalia. They are by no means found in all classes of deposits belonging to this period, since most of them are of marine origin; but here and there, in old lake-deposits, in ancient river-beds, in caves, and in dried-up bogs and swamps, they are numerous, and so varied in the multiplicity of their types that this period has frequently been designated the "age of mammals." In rocks more ancient than the Cretaceous, the mammalian remains, such as they are, few and fragmentary, are indicative of a type more nearly marsupial in character than anything else, and apparently related to the lowly forms, kangaroo-rats, etc., which to-day constitute the Australian fauna. The oldest known forms are perhaps *Dromatherium* and *Microlestes*, both of them from the Trias.

In the history of no other group of organisms do we find a more distinctly marked progression in development than is furnished by the Tertiary quadrupeds. The complete chain of structural modifications which certain groups present, and the steady and growing approximation of the unfolding fauna to the fauna of our day, constitute, perhaps, the most convincing demonstration of organic evolution. About one-half of all the existing orders of quadrupeds are represented in the first stage of the Tertiary period (Eocene); these are the marsupials, insectivores, rodents, whales, hoofed animals (ungulates), bats, lemurs, and possibly monkeys. In addition to these, there are a number of orders which have no living representatives at the present time; among such may be mentioned the *Amblypoda*, which perhaps stood not far in their relationships from the elephants, and comprised, among other forms, ponderous tusked animals (*Dinoceras* or *Uintatherium*), which rivalled the elephant in proportions; the *Creodonta*, or primitive carnivores; and the *Condylarthra*, or primitive hoofed animals. (Plates 60, 61, 62.)

In the middle Tertiary, or Miocene, we find representatives of the additional orders of edentates, or toothless animals, true carnivores, sirenians (dugongs), elephants, and monkeys; and among actual forms of to-day (although the exact species may be different), there are the hedgehog, mole, porcupine, beaver, squirrel, rabbit, tapir, rhinoceros, hippopotamus, hog, deer, giraffe, elephant, cat, dog, and hyena. In the older (Eocene) period, the bats are seemingly the only immediate representatives of the modern fauna. In the upper Tertiary, or Pliocene, there is a still further

Plate 59.



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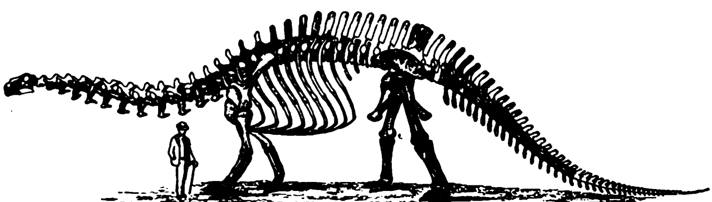

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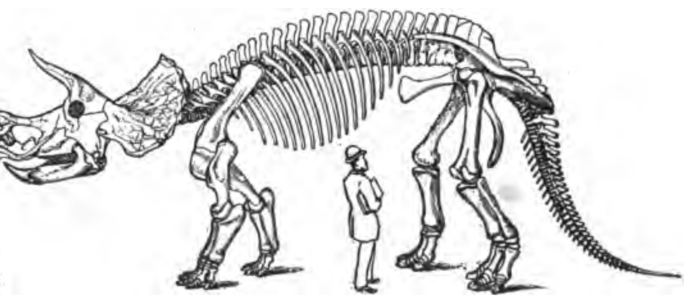

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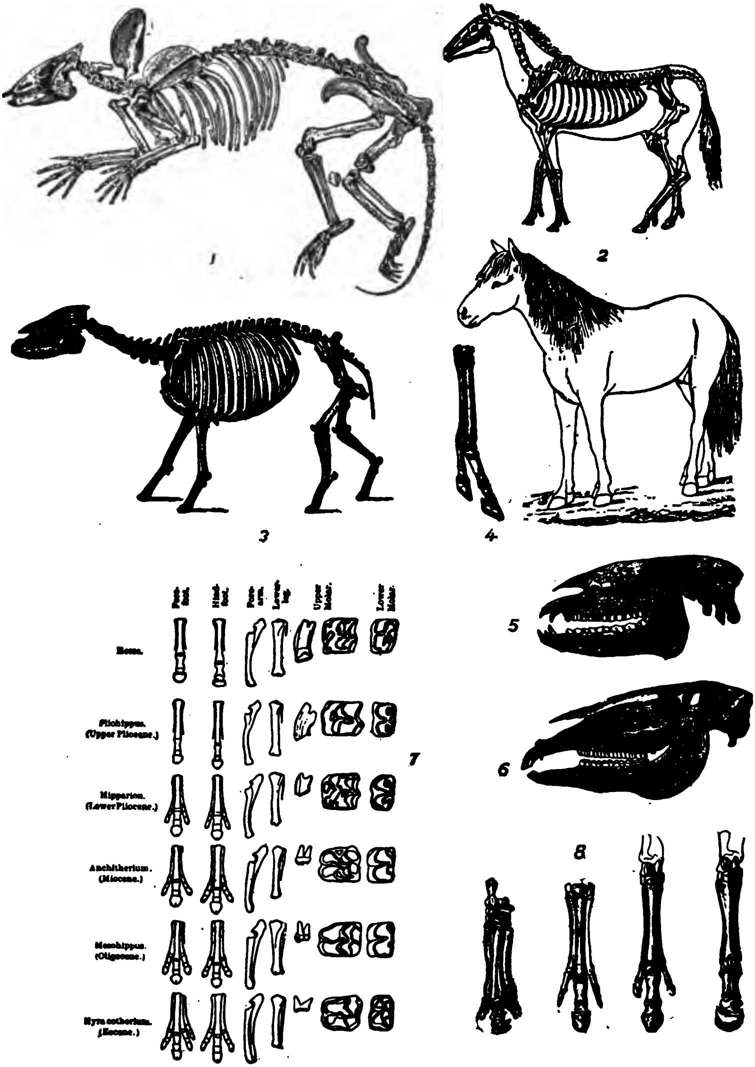
FOSSIL REPTILES FROM THE WESTERN UNITED STATES.

1. Stegosaurus, from the Jurassic deposits.
2. Brontosaurus (Jurassic).
3. Triceratops (Cretaceous).

(Restorations by Prof. Marsh.)

Plate 60.



ANCESTRAL FORMS OF THE HORSE (mainly after Marsh and Cope).

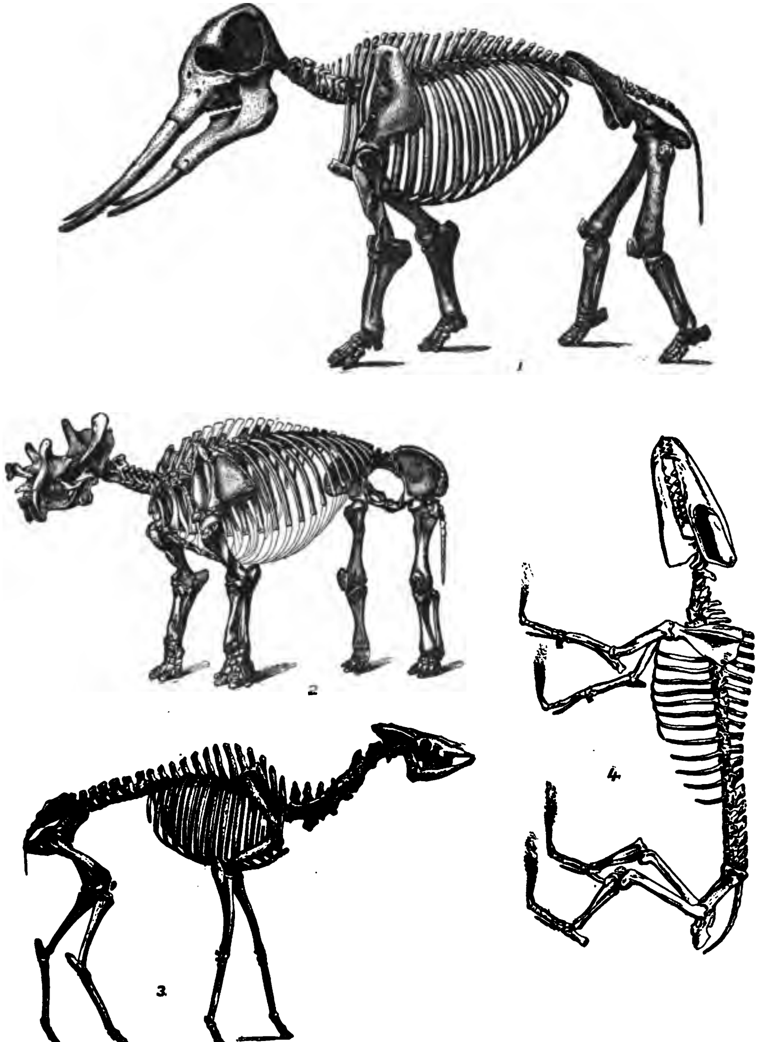
1. Phenacodus, earliest form, from the Eocene of Europe and America. 2. Hipparion (Pliocene and newer Miocene). 3. Paleotherium (Eocene of Europe). 4. Recent two-toed horse. 5. Skull of Paleotherium. 6. Skull of living horse. 7. Successive forms of the American horse-type, as illustrated by the structure of the feet and teeth. 8. Stages in the development of the European horse, from Paleotherium (on the left), through Anchitherium and Hipparion, to Equus (modern).

approach to the fauna of to-day in the introduction of an additional number of existing types, such as the sheep, goat, and ox, the bear and camel, and among monkeys, the macaque. Indeed, the greater number of the genera are identical with the genera of to-day, and even a limited number of living species appear for the first time. One of these is the common hippopotamus, which consequently represents about the oldest type of existing quadruped. In the Post-Pliocene period, the correspondence between the existing and extinct faunas is still further increased through the large preponderance of recent species. On the borderline of this and the preceding period we meet with the first unequivocal remains of man himself.

Origin of Existing Faunas. — It can be said, in a broad way, that the existing fauna of any given region is most closely related to the fauna whose remains are found in the same area, in deposits immediately preceding in age those of the present era. The North American, European, and Asiatic faunas, for example, are strictly a development from the Post-Pliocene faunas of approximately the same regions; the remarkable edentate fauna of modern South America — the sloths, armadillos, and ant-eaters — is foreshadowed in the giant *Glyptodon*, *Mylodon*, and *Megatherium*, and their allies; and similarly, the diverse marsupial fauna of the Australian continent is represented by the extinct *Diprotodon*, *Thylacoleo*, etc. Naturally, a part of every extensive fauna is the result of incoming of forms from beyond the border; it has been made such through immigration. It has been possible in a few instances to trace the lines of migration which were taken by certain animal groups, since it is known that they appeared earlier in time in some regions than in others. Thus the elephants, bears, swine, oxen, sheep, and antelopes appear earlier in the Old World than in the New, and presumably there was a migration of these animals in the direction of the Western Hemisphere; conversely, the true dogs seem to have been first developed on the American continent, and then to have made their way to the Old World. With all, however, it must be said that our knowledge on these points is hardly precise enough to permit us clearly to indicate the actual lines of migration. (Plate 62.)

Ancestral Forms of Animals. — The close study of fossil remains has permitted the tracing back of a number of our existing animals through their own lines of descent — that is to say, to early forms largely unlike themselves, from which they were by the slow processes of evolution developed into their present form. This reconstruction of "parental lines" has been done for some of the dogs, bears, and cats, for certain deer, the camel and the horse etc., and for none more completely than the horse. Plate 60 illustrates the respective modifications, seen plainly in the elimination or modification of certain elements of the foot and leg, — reduction in the number of the toes, abortion of the splints, etc., — which bring the modern horse, through various polydactyl forms, from its most ancient progenitor, the full five-toed *Phenacodus*, to its existing shape. Phenacodus, which was an animal hardly larger in size than a fox, belongs to the base of the Eocene series of deposits. As if in proof of this serial modification, the common horse even to-day shows a tendency to poly-

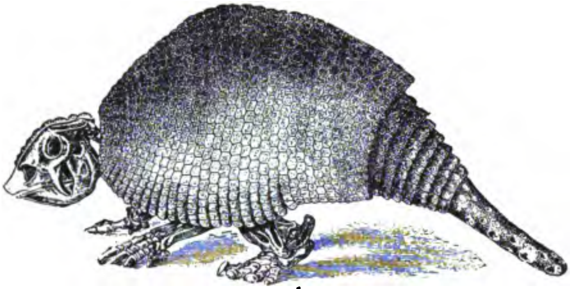
Plate 61.



RESTORATIONS OF QUADRUPEDS OF THE TERTIARY PERIOD.

1. Mastodon angustidens (Miocene).
2. Uintatherium (Eocene of the Western United States).
3. Helladotherium, a giraffe-like animal from the Pliocene of Greece.
4. Oreodon, a hoofed animal from the Miocene of the Western United States.

Plate 62.



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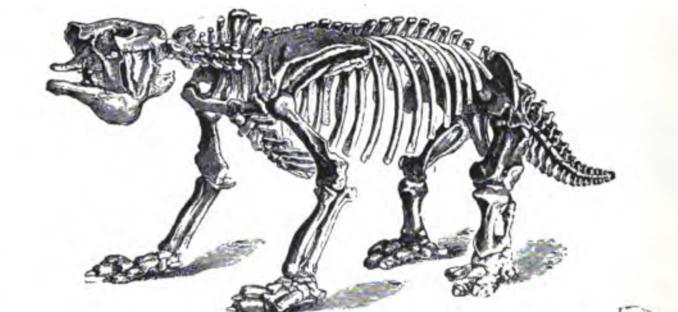

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FOSSILS OF THE POST-PLIOCENE PERIOD.

1-3. Giant edentates. 1. Panochtus (glyptodon). 2. Megatherium. 3. Mylodon.
4. Skull of Machairodus or Smilodon, a sabre-toothed cat.

dactylism; and instances are not rare where two (and less often, three) more or less functional toes appear on the animal, the indication of a reversion to its primitive or ancestral type.

The Age of Man and the Mammoth. — It has been the custom with some geologists to speak of the latest geological period as the "age of man and the mammoth," implying that in the association of these two organic types there was a marked characteristic implanted upon the faunal chain of the world. This division of time is, however, an unnatural one, and one that is not made a unit by its own construction. The oldest remains of man are of too infrequent occurrence to permit of a positive statement as to his antiquity; and they are, moreover, not coexistent in full time with those of the mammoth. That he was a contemporary of the great elephant is established beyond question, and it is about equally certain that he lived with the other great proboscidean, the mastodon. Both of these elephants are to-day extinct, the mammoth surviving until so recent a period as to have its carcass (frozen in the soil of Siberia) preserved with the flesh, skin, and hair still ensheathing the osseous framework. The mammoth and mastodon inhabited both continents, the remains of the latter extending back to the Miocene period.

The researches of late years make it almost certain that the oldest man of which skeletal traces have been found represented an inferior type as compared with the man of to-day. A limitation of brain capacity, depressed arch of the skull, and strong forward development of the orbital roof, suggest direct relationship with the higher apes, or at least a degree of development not very much above them. This is indicated in the specimens of Neanderthal (Germany), Shipka (Bohemia), and Spy (Belgium), and in an anomalous erect organism (*Pithecanthropus*) recently discovered in the late Tertiary deposits of Java, and by some classed as man, and by others (with probably more justice) as a connecting form between man and the ape.

PART II.

PHYSIOGRAPHY AND ECONOMIC GEOLOGY.

CHAPTER XVI.

THE PHYSIOGNOMY OF THE LAND-SURFACE.

Physiognomy of Continents. — It is a common teaching in text-books of physical geography that the continents have a generally identical structure, being built up of opposite mountain chains, with a great central depression between them, and adjoining littoral plains. Thus, if we take the continent of North America as our type, we find (illustrated by the region of the United States) the lowland plains of the Atlantic and Pacific borders, the Appalachian and Rocky Mountain systems respectively in the East and in the West, and between them the great depressed land of the Mississippi basin, which, gently rising eastward to the western foot of the Alleghanies, and westward to the eastern foot of the Rocky Mountains, attains elevations of 1,500 and 6,000 feet. This form of construction in a measure adjusts itself to the continent of South America, somewhat less so to Asia, and not at all to Europe, Africa, or Australia. In Europe the main mountain axes are disposed largely at right angles to one another (Scandinavian Alps, Pyrenean-Alpine system), and the depressed plains of greatest extent (North Germany, Russia) are not caught up between them. In Asia, lofty mountain chains (Kuen-Lun, Thian-Shan, Altai) occupy the heart of the continent; and in Africa, much of the central interior is a lofty plateau which cannot even be said to be supported by bounding mountain chains.

About the only points of unity that the different continents have with one another are their expansion on the northern side, contraction toward the south, whether of the main mass or of their peninsular parts, and the close bordering of mountain chains to present or past coast-lines. No absolutely satisfactory explanation has yet been given for the first characteristic; the second finds its solution in the fact that the border-line of continents and oceans is preëminently a line of weakness in the crust, and along it are, or were, reared up the newly forming and formed mountains; or any very large breakage within a continent itself, resulting in the formation of an interior sea, is likely to result in mountain-raising along its borders. This condition we have seen exemplified in the Mediterranean area, with the uplifting of the Alps and their continuations. Continents expand seaward by having mountain masses thrown out seaward; they retreat from the sea also with the formation of mountain masses; but these are interior, and face a breakage within themselves. Hence, the relation existing between mountain lines and the lines of sea-shore.

The fact that a number of mountain chains lie considerably inland from the sea — Altai, Carpathians —

is no indication that they were not formed at or near the sea-border. Since their upheaval, new land has formed on the outside, either through a recession of the sea (or upheaval of the land), or through a down-wash of continental sediment. Of such semi-alluvial construction is much of the bottom-land which acts as a base to the Rocky Mountains, the Alps, and the Himalayas, and the off-flow of the Asiatic Mountains northward through Siberia and eastward through China. No mountain chain is of newer date than much of the land which separates it from the nearest ocean.

The continental coast-lines of the western side of America and of the eastern side of Eurasia are largely determined by, or stand in direct relation with, the trend of a main mountain system. On the west side of Europe and the east side of America this is much less markedly the case; and a number of prominent mountain backbones traverse the trend of the main coast, and abut directly upon the sea. Such, for example, are the Pyrenees and the mountains of Spain, and the ridges which in sharp and prominent lines traverse, in a north-east and south-west direction, Scotland, Newfoundland, etc., and define for them those serrated projections into the sea which make their ragged fjord-shores. Such mountain-invaded coast-lines, frequently designated *rias*-coasts, indicate breakages; the mountains extended farther in the line of their trend, and have disappeared beneath the sea through probably successive falls. The Pyrenees and the mountains of Spain at one time extended far oceanward, and the ridges of Scotland connected with the outer ridge of the Scandinavian peninsula. The Orkneys, Shetlands, and Lofotes are the remnants that attest this breakage.

Physiognomy of Mountains. — In their exterior dress mountains present themselves in a multitude of forms, from the isolated mount and the parallel-trending ridges to a most complex system of elevations. Further, they vary from forms which, like the major part of the Alleghanies, have a uniformly monotonous or undulating aspect, to those in which ragged and serrated summits, dominant peaks, and beetling cliffs are the marked characteristics. The older the mountain the more uniform, gentle, or monotonous is likely to be the contour that defines it; for in the ages of its existence whatever sharp features may have been incised into it will have become blotted out through the never-ceasing action of erosion. A good type of such an ancient monotonous mountain is furnished by the even-backed Alleghanies and the Blue Ridge, in which the "peak" element is largely wanting. The newer the mountain, on the other hand, unless it be too new, the more likely are discordant or emphatic features to be determined. The work of destruction is sufficiently energetic to carve out dominant features, while the length of time has not been sufficient to efface them. In the Alps, Rocky Mountains, and Himalayas we have good examples of such ragged and comparatively new mountains.

It is, however, an error to assume that old and new forms can always be readily distinguished by their types of contour. The ancient White Mountains of New Hampshire, although of less height, are as rugged in their contours as perhaps the greater portion of the Rocky Mountains; and among the old mountains of

Plate 48.

1.

2.

THE PHYSIOGNOMY OF MOUNTAINS.

1. The Aiguille du Dru, Savoy, France. 2. The Bee-Hive Mountain, Alberta, Canada. Two mountains of very distinct types of contour.

Plate 49.

1.

2

THE PHYSIOGNOMY OF MOUNTAINS.

1. The Wetterhorn, Switzerland, one of the most precipitous mountain faces of magnitude in the world; the convolution of its rock-masses is clearly exhibited.
2. The Book Cliffs, Utah, near the Green River — the terminal wall of a lofty plateau mountain.

Norway we find a development of peaks, needles, and sharp ridges which can well compare with some of the most startling effects of Alpine scenery. (Plates 48, 49.)

The most marked structural features in the outer dress of a mountain are the steepness of rise, the division of the top-line into peaks or pinnacles, and the hollowing out of the slopes into gorges, cloves, basins, and amphitheatres. These features depend upon the positions which the rock-masses occupy within the interior, and the work of destruction and denudation on the outside. There are few mountains that rise with the steep slope that the eye ordinarily pictures, the deception being often emphasized by from 20° to 30°. When a mountain is assumed to rise up "almost vertically," the actual measurement will determine the slope to be probably not more than 45° or 50°; and even this is an uncommonly severe rise. The great precipices themselves rarely exceed for their full height 60° or 65°; but even with this measure they would appear to the observer standing in front of them very nearly vertical, and under certain atmospheric conditions even to overhang. Such an appearance is presented by the giant walls of the Dolomites, in the Tyrol, and by that most imposing of European precipices, the 7,000-foot wall of the Wetterhorn among the Swiss Alps. Of less elevation, but with greater verticality, are the mountain faces which bound the picturesquely similar valleys of Lauterbrunnen in Switzerland, and the Yosemite. The most precipitous mountain face of considerable elevation in the Eastern United States appears to be Wallface Mountain, in the Adirondacks, fronting the celebrated Indian Pass. Mountains with well-marked precipice faces usually have their top surfaces gently falling backward, a condition that suggests for many of them a fault-upheaval in front.

The exaggeration in slope that appears for ordinary mountains applies equally in the case of volcanoes. It can be broadly stated that the "sugar-cone" effects to which geographies so frequently treat us do not exist. The cones of such lofty volcanoes as Cotopaxi, Popocatepetl, Fusiyama, etc., do not for their steepest parts much exceed 30° to 35°, and for their greatest lengths fall considerably below this measure. Yet even with this moderate slope the mountains are wonderfully imposing in their presence. The slope of Etna is reduced to 12° or 15°; while that of Mauna Loa, in Hawaii, is so moderate — about 5° to 7 — that the mountain aspect is almost entirely lost. (Plate 36.)

Peaks of real magnitude belong properly to mountains of comparatively recent construction, but in the case of the mountains of Norway they are not entirely absent from those of ancient date. They rarely rise even in their exaggerated types more than a few thousand feet above the crest-line which constitutes the true mountain-top, and it cannot be positively said that they ever rose much higher; in the case of mountains of low elevation, like those of the Appalachian system, they may drop to a thousand feet or considerably less, appearing sometimes as mere pimple elevations on the general mountain backbone. The White Mountains ridge in New Hampshire, of which Mt. Washington is the central figure, has some eight or nine peaks (Adams, Madison, Jefferson, Monroe, Jackson, etc.) rising out of it; but their elevations are retained within the thousand feet or so which mark the interval between the general height of the ridge and the top of its most elevated summit. The actual peak-elevations in the Catskills, although the mountains are themselves of considerably less magnitude, are higher than in the Presidential Range, rising as they do to positions of 1,300 or 1,500 feet above a general plateau elevation of some 2,300 feet.

The loftiest true peaks are found in the Himalaya and Karakoram Mountains, where there is an actual elevation above the crest of some 6,000 or 7,000 feet, and exceptionally perhaps even more. Closely following these is the famous Matterhorn of Switzerland, which in the abruptness of its demarkation stands preeminently as the type of what is frequently designated "Alpine peaks"—a term always inappropriately applied to the peaks or summits of the Appalachian mountains, and having but restricted application even in the case of the Rocky Mountains. Pike's Peak, with an absolute elevation of 14,147 feet, rises as a mountain 8,000 feet above its base opposite Colorado Springs; but the peak itself barely exceeds 2,000 feet.

In this consideration no account has been taken of volcanic mountains, whose cones are frequently spoken of as "peaks." These rise as individual objects considerably higher than the true mountain peaks, in fact, to nearly twice their height. Thus, Ararat has a clear sweep of about 13,000 feet, Fusiyama of about 12,000 feet, and Popocatepetl (and Orizaba) of 10,000 feet above the surface of the Mexican plateau; the last-named presents a mountain face of nearly 15,000 feet to the bottom-land from which it sweeps up in its most graceful form.

The true mountain peaks depend at times for their existence upon rock-dislocations; i.e., they have been run up higher than the crest which supports them by the rocks having been actually forced up in the positions which they now occupy. More frequently, perhaps, they are in the main only an expression of the irregular wear of the mountain mass, standing up as a relief in rock-resistance. The physiographic features that associate themselves with mountain peaks and with mountain summits generally, cannot all be referred to in this place, but a few of those best known in the language of mountain craft are the following: The *Col* (*Juch*, saddle, or yoke): the crest or divide which unites two mountain peaks. A good example of such col, although on a small scale, is the concave ridge ("saddle") which unites Mts. Lafayette and Lincoln in the Franconia Mountains. *Arête:* a sharp ridge of rock into which the col may develop, or any similar narrow rock-wall that may protrude from the mountain face, or in which the mountain may terminate. Some of the arêtes are so sharply cut that they can be readily straddled. *Aiguilles* (needles): the exceedingly sharp pinnacles into which a mountain crest may be worn, a structure beautifully shown in the ragged and serrated crest of the Argentière group of the Mont Blanc mountains. A largely similar structure, although lacking the needle-like terminations, is that seen in the "saw-tooth" crest of the Sawback Mountains of South-western Colorado, and in the so-called *Karren* of the limestone Alps of Carniola, Dalmatia, etc. *Cornice:* an impending part or true cornice of a mountain. More generally the term is applied to snow-fields that occupy this position, and in which there is a vertical terminal wall. *Couloir:* a hollow or basin which lines up to an arête or col, and occupies a position usually below the full summit of the mountains. It is oftentimes the receiving-basin for the formation of glaciers of the second magnitude. *Massif:* the great mass, buttress, or nucleus of a dominating mountain. *Clove:* a recess cut by water-action into the wall or heart of a mountain which has not yet developed into a full valley. In some of its accepted forms it is synonymous with gorge, ravine, or defile; but perhaps with clearer definition it should apply only to such recesses of generous development as terminate abruptly in the mountain itself, and which lead up to an amphitheatre or circle (*cirque*). The Kaaterskill Clove, in the Catskill Mountains, and the upper valley of Gavarnie, in the Pyrenees, may be taken as the type of this structure.

In their inner dress, or in the relations which they hold to the rocks which build them up, mountains follow a number of distinct types. Their dependence upon rock-foldings, making the "anticlinal" and "synclinal" mountains, has already been pointed out in Chapter IV.; and it now only remains to indicate one or two types of construction which are either entirely independent of this form of rock-movement, or are in such a way connected with them as to make the association not readily discernible. The one type may be designated "faulted mountain," where the elevation has been brought about through an uplift along a line of fault; or much the same form of relief (relative elevation) will result from a downfall along the line of faulting. Where a number of movements have followed on distinct but parallelly placed lines of faulting, bringing into sharp relief successive "blocks" of the earth's crust, we have presented that type of mountain construction which by American geologists has frequently been designated the "Basin Range type," from its representation in the Great Basin.

In what is known as the "monoclinal mountain," we have hardly more than an unimportant modification of the type that has just been described. The strain that in the one case has caused absolute disruption of the rock-mass, with either upward or downward movement, has in the other brought about merely an abrupt bending (or "kneeing") of the rocks; it has produced a one-sided fold, or *monocline.* It cannot be overlooked, however, that in some cases the monocline is merely a greatly elongated anticline, in which the axis of the arch has been removed entirely to one side.

The Physiognomy of Plateaus and Plateau Mountains.—Plateaus in some regions of the earth's surface are hardly less significant physiographic features than are the mountain chains. Of two continents, at least, Africa and Australia, they are the dominant features; and in both Asia and North America they occupy a not insignificant portion of the entire area. In its more generally received definition, a plateau is any large land-area, not distinctively mountainous in its surface aspect, which occupies a high position above the sea. As such it presents itself to us in a variety of forms, not all of which have the same geological relation.

Two broad types may be easily recognized: "mountain plateaus," or such as have a distinct relation to the rearing up of mountain chains, and are secondary to them; and "continental plateaus," of much greater extent, which are independent of primal mountain formation. Good examples of the first class are found in the high lands, of 10,000 to 13,000 feet elevation, that are held up between the enclosing walls of the Andes, in somewhat similar regions of the Rocky Mountains, and in the flattened-out parts of the Appalachian Mountains, and as we find them in the Pocono Mountains of North-eastern Pennsylvania, in the Catskill Mountains of New York, and in the Cumberland Plateau mountains of Tennessee. In the examples last named, the rocks depart but little from the horizontal position, and consequently do not partake of that folding and plication which might be said to be the essence of mountain-making. Yet the regions, through varying erosion, stand up prominently like every other mountain tract, and justly lay claim to being considered mountainous. Where cut out of plateau masses of this kind, the elevations may properly be designated "plateau mountains." (Plate 49, Fig. 2.)

As types of the continental plateau, may be taken the great inner mass of South-central and East-central Africa, extending into the Soudan and Abyssinia, and covering (with an elevation of 5,000 to 10,000 feet) hundreds of thousands of square miles of hardly disturbed rock-strata. The great "Tertiary Plateau" of the Western United States, in Colorado, Utah, and Arizona, is an equally good type of this structure. On its eastern and south-eastern faces, where erosion has laid bare the thousands of feet of nearly horizontal strata out of which it is constructed, and equally in the numerous cañons that cut into it, the landscape is preeminently that of lofty mountains; the top level, on the other hand, presents the typical plateau surface. It seems likely that the uplift of this plateau, as well as of that of Africa, was brought about through a bodily "squeeze" of its rock-masses, the strata, while appearing horizontal, being in fact arched, but so gently and over so broad an expanse as to virtually escape detection.

Another type of plateau is furnished by the interior of Greenland, and by seemingly the greater portion of the central mass of Mexico. In the former the accumulation, through ages, of falling and drifting snow, has blotted out the normal mountain and valley features of the land, and raised the surface to a general level of 6,000 to 10,000 feet elevation — the most uniform plateau surface that is known upon the face of the earth. Much the same form of construction is to be found in the Mexican plateau, except that in this case the filling in of the surface irregularities, or the making of the plateau, has been brought about mainly as the result of volcanic discharges — the outflow of lava and the pouring over it of an almost incredible quantity of volcanic ash.

The distinction which some geographers and geologists have attempted to establish between plateau and table-land has not met with general acceptance, and is not founded on sufficiently important characters to warrant recognition.

The Physiognomy of Valleys. — Valleys properly divide themselves into two broad groups, — valleys of the mountains, and valleys of the open country. The latter are more generally low-lying, and at times represent merely the old sea-bottom which has been laid and kept dry without undergoing serious modification; of this type are the main valley of the Mississippi and most of the river valleys that lie on the coastal plain of the United States. At other times these large open valleys are the made land of river sediment — a reclamation of territory from the sea. Such are the great "plains" of much of low-lying China, the "Netherlands" of Northwestern Europe, the valley of Lombardy and Venetia, of the lower Ganges, etc. As a type of the great open valley occupying a high position may be cited the western half of the Great Plains which lie between the Mississippi River and the base of the Rocky Mountains — the valley of the Platte, etc. Here we have an extensive area of fairly ancient sea-bottom, elevated to some 5,000 or 6,000 feet, in which mountain features have, for one reason or another, not yet been developed. The River Platte flows on the surface, instead of cutting its way down in the manner of the more westerly cañon streams. In the absence of those sharply defined mountain features which define the cañon region, — features that have been worked out mainly as the result of water erosion, — we prefer to call this surface "plains" or "valleys," in preference to plateau (with its valleys lying deep down in the cañons); but manifestly the distinction of terms has here little or no significance.

Mountain valleys are such as originated within mountain areas, and were determined as the result of mountain-making. Their relations to the trend of the mountains, whether longitudinal or transverse valleys, and their significance as features of water erosion, have been explained in Chapter IV. In their topographic aspects, such valleys differ from one another, apart from the matter of size, primarily in the contours of their boundary walls and in the width and inclination of their floors. Broad and flat valleys belong in the main to the lower mountain tracts, where the work of water reconstruction, the deposit of sediment, in great measure counterbalances the work of denudation, and where the latter represents the combined work of a number of streams united into a single one, with broadly distributed labor, instead of labor in a restricted area. In such valleys the abrupt and rugged features of the landscape have been largely blotted out, and a gently flowing outline has been substituted. The boundary walls slope up easily; and between them is a generous expanse of flat country — the valley itself. Geologists have been in the habit of characterizing valleys of this description, from the form of their cross-section, U-shaped valleys, in distinction to the abrupt passages — gorges, ravines, cañons, etc. — which belong more properly to the upper mountain tracts, where the tumultuous energy of single streams is largely emphasized, and where the contained sediment acts in itself as an eroding agent rather than as an agent tending to cover up the work of destruction by its own deposition. This type is known as the V-shaped valley. (Plates 17, 18.)

In their dominant types these two forms of valleys have dually different significations: in the V-shaped valley, nearly all the energy is directed to down-cutting; at least the cutting in this direction is far in excess of the lateral destruction of the boundary walls through ordinary atmospheric agencies. Hence, the sharpness of the cut and the closeness of its confining walls. Especially is this condition emphasized in dry and arid regions, such as the western cañon region, where there is a greatly restricted rainfall, but where powerful streams are yet present. The V-shaped valley broadens out with age, and ultimately loses its distinguishing characteristics. It is, consequently, spoken of as a young feature in the landscape. In the U-shaped valley, the lateral destruction keeps pace with, or even far exceeds, the downward cutting, and thereby obtains its open and flowing outlines. It is oftentimes merely an extension in time of the V-shaped type, and hence is regarded as an old feature in the landscape; but the valleys of this type are not all necessarily ancient.

There is a third type of valley, much less abundant than either of these two, which differs from them in the marked flatness of its floor, its open extent, and the comparative steepness of its boundary walls. These are the valleys which are or recently have been occupied by glaciers, and have been doubtless largely fashioned by them. The ice, itself eroding in part, and as a cover preventing erosion by the atmospheric waters, has thus produced a contour which may be said to lie intermediate between the two types that have been described.

Physiognomy of the Coast-Line. — The most obvious distinctive features which coast-lines present are embodied in the presence or absence of indentations, and in the presence or absence of prominent elevations (bluffs, cliffs, promontories). The closed, or regular, coast, is well developed around the continent of Africa and over the greater extent of the Pacific side of America; the irregular, or indented, coast, finds its expression in the Atlantic border of Europe and in the Pacific contours of Asia. Again, the bluff coast is the characteristic coast of Great Britain, while the flat coast distinguishes most of the Atlantic and Gulf borders of the United States.

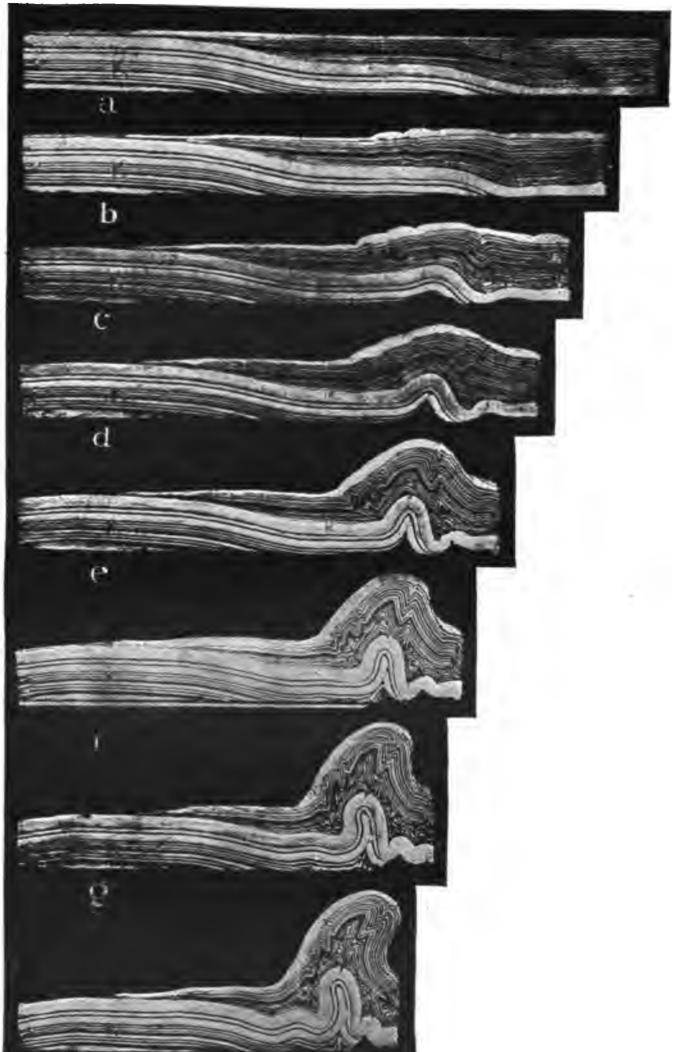
The contours of coast-lines are often an index of the special phase of movement that characterizes a given continental area. Thus, the largely indented coast, and the coast with prominent headlands and defining land-cliffs, generally determine a region which is now, or has been recently, undergoing subsidence, or over which the sea is rising; the closed coast, and coast with extensive flat reaches, on the other hand, commonly define a region of actual or recent elevation, or one from which the sea has only latterly receded. This is made clear when we recall that the ocean, as an agent in the equal distribution of material that is carried into it, tends to even up all irregularities, whether boundary or elevatory, and consequently to build out under its protecting waters a uniform platform. This, on elevation or through a rècession of the waters, would appear as a great expanse of flat and closed shore-strand, much like the Atlantic littoral of the United States. On the other hand, a subsidence of the land or transgression of the sea would tend to a contrary result, to an emphasis, through the destroying action of the inflowing waters, of such irregular features as the land-surface may already have. It is in this way that bays are extended inward, promontories lengthened outward, and projecting headlands made steep and rugged by the incising action of the beating surf and waves.

The relation of mountains to coast-lines has been referred to in the sections devoted to the physiognomy of the continents and to that of mountains. Many coast-lines, especially those of flat reaches, are bordered by more or less parallel-trending islets and islands,— keys, lagoon-barriers, etc.,—as we find along almost the entire Atlantic coast of the United States, and again off the north-west coast of Germany (Frisian Archipelago). Such structures may originate as simple deposits in the line of oceanic currents, being in fact built up by them,—as in the case of the "hooks" and barriers which bound the American coast for the greater distance between Long Island and Florida,—or they may be the result of the breaking up of an ancient flat sea-front by an oceanic transgression or overflow. Of this nature appears to be the line of islands which lie north of Holland and Germany, and constitute the West and East Frisian Islands. Thus, the barrier feature belongs to both areas of stability and movement. The presence of lines of rocky islands and islets off a coast, as we find them, for example, in the Lofotes off Norway, the Shetlands and Orkneys off Scotland, the Aleutian Islands off Alaska, and the South Chilian Archipelago, is almost positive indication of recent continental dismemberment,—either as the result of direct continental subsidence beneath the sea, or of the rise of the water over the land. The main islands of Britain are themselves merely separated parts of the continent of Europe — the islands of Nova Zembla, the broken-off continuation of the Ural Mountains in the north.

The Physiognomy of Rock-Masses. — The general aspects of rock-masses have been referred to in Chapter III.; and it remains only to restate some of their fundamental characteristics, and to outline other essentials of construction and position which have not been referred to. Fully nine-tenths of all the rocks that are known to the geologist, barring possibly the more ancient rocks of the metamorphic series (gneisses, schists, etc.), concerning which considerable doubt still exists, are transformed ocean sediments, inorganic and organic (limestones). As such they were accumulated in the trough of the sea in either horizontal or nearly horizontal beds. The normal position of rock-strata, therefore, is one not departing rigidly from the horizontal; any broad departure is the result of disturbance following the making of the rock. From such disturbance have resulted the tilting, folding, overturning, faulting, and shearing which have stood the rocks vertically (or on their edges), pushed them over one another, broken them into sections and pieces, and thrown them into parallel-trending undulations (mountain folds). From these movements have resulted those types of structure which we have already learned to recognize as "anticlines," "synclines," and "monoclines," with their attendant "dips" and "strikes."

Anticlines (and necessarily also synclines) may vary from broadly open arcs to closely compressed zigzags, so close, in fact, that the opposite faces of the folds are

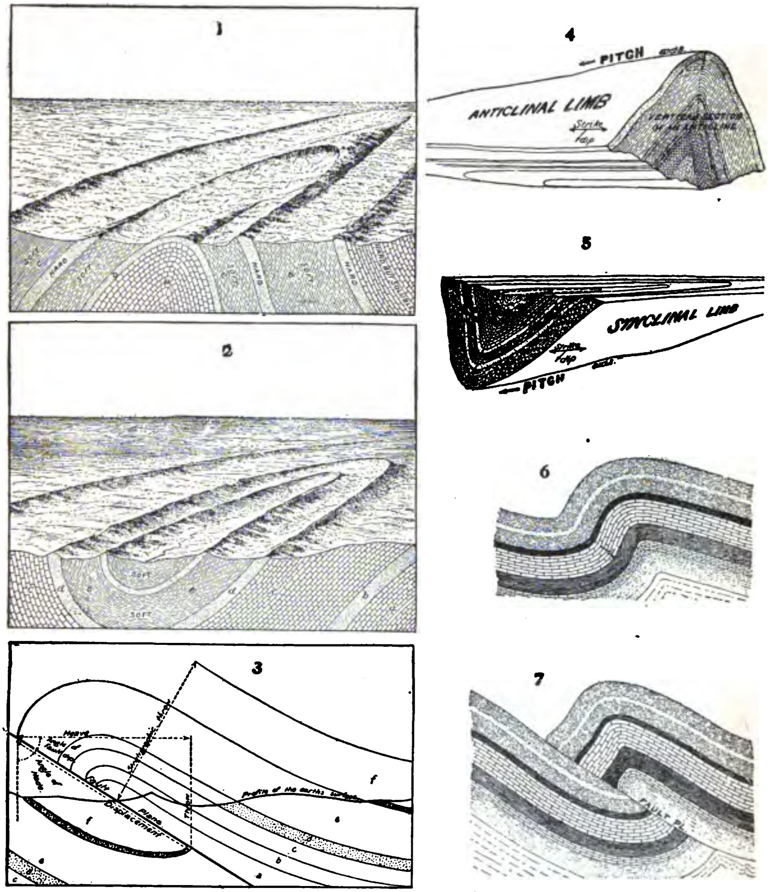
Plate 50.



THE PHYSICS OF MOUNTAIN-MAKING.

The results in "folding" obtained by squeezing together, from the ends, a series of superimposed layers of clay. The extent of pressure, with increase of folding, increases from *a* to *g*. A laboratory experiment (after B. Willis).

Plate 51.



ROCK FOLDS AND DISTURBANCES.

1, 2. The surface of a country, under erosion, with anticlinal and synclinal structure; the ridges occupy the positions of the harder rock. 3 Analysis of a fault. 4, 5. Analysis of anticlinal and synclinal folds. 6. An angulated fold in rock strata, with incipient fracture, leading to a fault. 7. Fault, with vertical displacement. (After B. Willis.)

made virtually parallel with one another. At such times it is frequently exceedingly difficult to determine the presence of a fold at all, the different rock-strata seemingly following one another in regular and direct sequence. A recourse to the mineral characteristics of the different beds, or to their contained fossils, however, will generally determine the involution, the identical bed recurring in two or more places in the same section. In the making of an anticlinal fold two kinds of strains are generally imposed upon the rock-masses: the outer beds, by reason of their long movement, are pulled apart, while the inner beds are in a measure compressed through shortening. It results from this, that fractures and lines of weakness are developed on the anticlinal crests, which are rapidly taken advantage of by the eroding waters in their general course of destruction. Manifestly, so far as the position of the rocks is concerned, the opposite result is brought about in the synclinal fold.

Anticlines may stand singly by themselves, or, as is more often the case, a number may follow one another in close succession and parallelism. The ridge of the anticline, the summit-line of which determines the direction of trend, or strike, of the rocks, is frequently designated the "anticlinal limb;" its natural crest, while it often is a horizontal line, need not necessarily be such, but may decline rapidly to the horizon, or even alternately rise and fall. These irregularities, after denudation has materially modified the original relief of the land, are the cause of much complexity in the surface contours of the different rock-strata; the "rounding off" of strata, surface disappearance, "spooning," etc., are conditions with which the geological student will sooner or later familiarize himself.

Unconformity in Succession. — Were the materials of all the forming rocks of any one region permitted to accumulate and develop without hindrance or disturbance of any kind, the rocks that would be formed from them ultimately would succeed one another in regular conformable lines or strata; the inclination or dip of one stratum would be the dip for all. Examples of such regular succession are known in many parts of the world for thousands of feet of thickness of rock. But it is equally true that, after certain series of rocks had been made, they were subjected to more or less violent movements, which had the effect of disturbing their normal positions; over these, at a subsequent period, new rock material was again laid down, and in a normally horizontal position. A condition of *unconformity* has here been established. Unconformities of greater or less degree occur in nearly all regions where two or more geological formations are represented. They offer a certain time-measure in tracing the geological development of a country, inasmuch as they are the index of the amount of work (and consequently of the time required to do this work) that has been accomplished since the rearing up of the earlier rocks, and the disposition of the newer rocks on top of them. Frequently the older rocks show barely more than a trace of wear along the divisional line; at other times they have undergone extensive erosion, or have, in fact, been even eroded almost to a basal level.

Geological Breaks. — Under this term geologists understand the condition when a hiatus or gap intervenes between the formations of any given region; for example, where the Carboniferous formation immediately follows the Silurian, leaving out the properly intermediate Devonian which is developed elsewhere; or, where possibly the Cretaceous rests directly upon the Carboniferous, with the Permian, Triassic, and Jurassic eliminated. Occurrences of this kind are indication that vast periods of time had elapsed between the deposition of the older and the new rocks, periods sufficient in which to have accumulated, in more favored regions, the deposits that normally compose the geological column. The fact that the Devonian deposits are wanting in region A, and the Permian, Triassic, and Jurassic in region B, is generally taken to indicate that, during the periods when those deposits were forming elsewhere, regions A and B were removed from the ocean, — i.e., elevated out of it, — and could not receive marine deposits of those times; and that this conception is in a general way a correct one is proved by the fact that areas which are deficient in marine deposits of a given period frequently show in their surfaces deposits of terrestrial and fresh-water origin, or such as would be formed on a dry-land area. Gaps of this kind may be measured by an interval of but a few thousand years or less, or they may extend over hundreds of thousands of years, time sufficient to have completely changed the character of the world's faunas. Hence, we frequently find in strata placed in immediate juxtaposition the most diverse types of plant and animal life represented. Such diversity is always an indication of a vast passage of time, of a big geological break.

Characters Impressed upon Rock-Masses. — The presence in the solid rock of many of the distinctive features that ordinarily belong to muds and sands, such as footprints, raindrop impressions, ripples, and sun-cracks, has already been referred to, and their proper relation to the acting physical forces pointed out. There are other well-impressed physical characters in the rocks, explainable likewise through known causes; but they need hardly be considered here. Reference is only necessary to what are known as "current-bedding" — the rapidly alternating and shifting stratification which has been brought about by irregular currental deposition, as when near the mouth of a stream or in a delta — and the "flow-and-plunge" structure, a wavy stratification due to a plunging flow of a stream when depositing its sediment.

CHAPTER XVII.

SOME OF THE COMMON AND MORE USEFUL METALS AND MINERALS.

Gold is a widely distributed mineral, and is usually found in association with quartz veins of mountainous and volcanic regions, or among the washings (sand, gravel, river-mud) that have been derived from the destruction of the parent rock. Its more general form is that known as "native gold," which is an alloy of about ninety per cent pure gold and eight or ten per cent silver; all native gold has silver with it, and in the substance known as *electrum* the quantity of the latter amounts to about twenty per cent. Common or native gold is a soft, highly ductile and malleable metal, heavy in weight (about nineteen times the weight of water), and free from tarnish; in the solid rock it occurs as strings, flakes, and crystalloids, frequently in association with iron pyrites, and occupying cavities in the "rotten" rock which have been left by their decomposition. In the river-washes, "placer" deposits, it is also found in flakes, grains, and scales, and at times as "nuggets" of considerable size and weight. Two nuggets from the Victoria region of Australia weighed respectively 2,280 and 2,166 ounces. The most productive gold regions in the world are those of the Western United States (California, Colorado, Dakotas, etc.), Australia (Victoria, New South Wales), Russia and Siberia, and South Africa; in the last-named region the greater part of the output is from the conglomerates of Witwatersrand.

Much of the silver and copper that are mined contain gold mechanically mixed up with them, a circumstance which makes specially profitable the mining of these minerals; a less frequent association is with the sulphur ore of lead (galena). Gold hardens through alloying with copper and silver; the former tends to give the compound a reddish-yellow color, and the latter a distinct greenish shade. In the gold coin of the United States copper is present in about a tenth part. The metal virtually resists all ordinary acids, but is soluble in a mixture of nitric and hydrochloric acids (aqua regia). A compound of gold and tellurium makes the rich white ore known as *Sylvanite.*

Silver occurs in a much greater variety of forms than gold, since it easily unites with certain mineralizers (such as sulphur, bromine, chlorine, etc.), to form a number of distinct ores. As native silver, which is not common except as an alloy of gold, it occurs in long stringy and wiry masses, which are easily folded and twisted upon themselves; also in flakes, scales, and crystals. A specimen of native silver from the mines of Kongsberg, Norway, and now in the royal collection at Copenhagen, weighs upwards of five hundred pounds. Like gold, silver is mainly associated with the crystalline and igneous rocks, occurring in veins, lodes, and pockets. It is a soft, highly ductile and malleable metal, with a specific gravity, as compared with water, of about 10.6; its normal color is silver-white, but it readily tarnishes, and the presence of only minute quantities of sulphur gas in the atmosphere causes it to enter into combination and turn black. Native silver readily dissolves in nitric acid (forming the nitrate of silver), from which it can be easily separated (precipitated) by the addition of a chlorine compound, to form the chloride of silver.

The greater part of the world's silver is not obtained from the native metal, but from one of its several ores, more commonly the black sulphur ore (sulphide), *Argentite*. Two forms of red sulphur silver are known as *Pyrargyrite* and *Proustite*. An exceedingly soft compound of silver is the natural chloride or horn-silver (*Cerargyrite*), which can be cut almost as easily with the knife as resin. Apart from these sources of supply, an important repository of the metal is found in the sulphur ore of lead (galena), which in many regions is highly argentiferous. The most important silver producing countries to-day are the United States (Nevada, Montana, Colorado, etc.), Mexico, Bolivia, Australia, Peru, etc. In coin-silver the alloy copper makes up about the one-tenth part.

Copper occurs native in strings, grains, plates, and masses, the last sometimes of gigantic size; a specimen is recorded with a weight of four hundred and twenty tons. It is a soft but heavy metal (with a specific gravity of 8.8), and can generally be recognized by its distinctive copper color. It possesses in an extreme degree the properties of malleability and ductility, and is an excellent conductor of both heat and electricity. One of the principal uses to which it is put at the present day is the making of copper wire for the conduct of the electric fluid, largely in connection with the trolley service. A large proportion of the world's copper is obtained from the natural metal, with which is frequently associated a workable quantity of gold and silver ("auriferous" and "argentiferous" copper); but various ores, such as the oxide of copper (*Cuprite*), and the sulphides of copper and iron (*Bornite*, *Chalcopyrite*), contribute largely to the general supply. The leading countries furnishing copper are the United States (Michigan, Arizona, Montana), the Iberian Peninsula, Chili, and Japan. The most extensive single deposit of the native metal appears to be that of Keweenaw Point, in the northern peninsula of Michigan, where is located the famous Calumet and Hecla mine (depth upwards of four thousand feet).

Copper is not restricted to any one class of rocks, but its largest association is with igneous masses and with the older altered series (sandstones, conglomerates, etc.). Alloyed with zinc, it makes brass, and with tin (in from ten to twenty per cent), bronze, and gun and bell metals; statuary bronze is usually a triple compound of copper, tin, and zinc. Of the more familiar ores of copper is the "brassy" sulphide of copper and iron known as copper pyrites or chalcopyrite, which has a certain resemblance to gold, and is sometimes mistaken for it; hence the name, "fool's gold." It can, however, readily be distinguished from gold by its brittleness, powdering up under the hammer or even under the well-pressed knife-blade. It is also soluble in nitric acid, whereas gold is not; and in addition it has a low specific gravity (about 4). From the second form of fool's gold, or iron pyrites, it is in most cases easily distinguished by its deeper coloring, and the fact that it can be cut with a knife, whereas iron pyrites cannot. A highly prized ore of copper, much used in decorative purposes, is the green carbonate, or *Malachite*, the finest specimens of which still come from Siberia; the blue carbonate, which frequently passes off by almost insensible gradations into the green form, is the beautiful mineral known as *Azurite*.

Zinc as a pure metal is not known to occur in a state of nature. That which is used in the arts is extracted from one or more of the zinc ores, most largely from the zinc sulphide—the mineral *Sphalerite*, or zinc-blende. This mineral is usually found in irregular (or partially crystallized) masses, of a translucent grayish or yellow-brown color, with a distinct resinous lustre. The last characteristic will probably serve to distinguish it more readily than any other. At times it has a decided "garnety" appearance; but its moderate hardness, 3.5 to 4, easily marks it off from garnet. There is a remarkable association between this ore and the common sulphide of lead (galena), the two being so generally found together in the same deposits that they are frequently spoken of as lead-zinc ores. What the nature of this association is has not yet been clearly determined.

Among the more important uses to which zinc is put is the manufacture of zinc-white (the oxide of the metal zinc), a substitute for the lead-white of paints. Alloyed with copper it makes brass, and in a different proportion the so-called "white metal." The coating of iron with zinc constitutes the process of galvanizing. Other, but much less common, ores which yield this very useful metal are the red oxide, known as *Zincite*, and the silicate (*Calamine*). The richest yields of zinc in the United States are in Missouri, New Jersey, and Pennsylvania.

Tin, if it occurs at all in a native metallic state, does so very rarely. Its most common ore is the oxide, when it forms the mineral species *Cassiterite*, or tin-stone — a rich brown, hard substance, distinguished in its crystallized form by a beautiful adamantine lustre and high specific gravity (about seven times that of water). It occurs disseminated through certain granite rocks; but elsewhere it is found in rolled grains and pebbles, the so-called "stream tin," and in kidney-shaped masses of a fibrous structure ("wood tin"). In the arts, tin is extensively used as a coating for iron, forming in union the well-known tin-plate. With copper, in various proportions, it constitutes the forms of bronze known as bronze proper, gun metal, bell metal, etc.; in combination with lead it makes pewter, and with antimony, Britannia metal. Outside of Mexico, the American tin deposits have little importance; the mines of Cornwall in England, and of Saxony and Bohemia, have been worked for centuries, and their product is largely supplemented by the output from Australia and the East Indian Archipelago.

Lead, which is one of the most familiar and useful of metals, and in its ore one of the most widely disseminated, is so rarely found pure in nature that it might almost be said not to exist. That which is commonly known to us as lead ore is a compound with sulphur, forming the mineral species *Galena*. It occurs in almost every kind of rock, from gneiss to volcanic extrusions and limestones, and in the form of infiltrated and penetrating veins, irregular accumulations, and distinct crystals. It is almost inseparably associated with the sulphur ore of zinc (zinc-blende), and hence the united mass is not infrequently spoken of as lead-zinc ore. At times it is largely silver-bearing (argentiferous); and this fact makes the mining of the lead profitable, when by itself possibly the baser metal would have yielded little in returns.

Galena is known to nearly all amateur mineralogists in the beautiful and very common form of cubical crystals, which, when not tarnished, may have an almost brilliant, although still leadeny, lustre. It is readily cut with a knife, being one of the softest of metals, and leaves a dark streak on paper. Its specific gravity is almost as high as that of metallic iron, about 7.5.

The various uses to which lead is put need hardly to be recounted. As an alloy with tin it makes pewter and common solder; with antimony, the substance out of which printers' type is manufactured ("type-metal"). In the making of leaden shot and rifle-balls, a small quantity of arsenic is added, which makes the lead somewhat harder, and in addition permits it to assume a spherical form when dropped through the air. The carbonate of lead furnishes the common white lead of painters; it is also the principal lead ore of the famous silver-lead deposits of Leadville, Colo. The largest lead-producing country to-day appears to be Spain, followed by the United States, Germany, New South Wales, and Mexico. There are a number of ores of lead which are highly prized by collectors for their beautiful colors; among such are the grass-green phosphate (*Pyromor-*

phite), the orange-red chromate (*Crocoite*), and deep red vanadate (*Vanadinite*).

Antimony as a native metal occurs but sparingly; it is a bright tin-white mineral, with a metallic lustre, and of only moderate hardness. The antimony of the arts is obtained from the sulphur ore of the metal, antimony glance, or *Stibnite*, of which Japan furnishes the largest source and the most beautiful specimens. These are elongated prismatic and somewhat spear-shaped (exceedingly brittle) crystals, of a bluish-gray color, and with brilliant lustre; at times they attain a length of nearly two feet or more. Antimony is mainly useful in the arts through the alloys which it forms with lead and tin, imparting to both greater hardness and durability. Type-metal is a compound of lead and antimony; Britannia metal is an alloy, in principal part, of tin and antimony.

Arsenic, like antimony, is rarely found pure in nature; and it, too, is a tin-white mineral with metallic lustre. Commercial arsenic is obtained principally from its two sulphur ores, *Realgar* and *Orpiment*, the former of a beautiful aurora-red color, and the latter golden-yellow. Both of them, although by no means abundant minerals, occur massive, and can generally be recognized by their distinctive coloring (and lustre) and exceeding softness; their hardness is but little above that of soapstone. The compounds of arsenic are extensively used in the manufacture of pigments, for preservatives, insecticide-poisons (Paris green, white arsenic), etc. In the making of leaden rifle-balls and shot, a small quantity of arsenic is added to the lead to give it greater hardness. The white arsenic (or simply, arsenic) of druggists is the oxide of the metal, and is obtained from the sulphur-arsenic ore of iron (mispickel) by roasting.

Nickel. — This metal is known to most persons in the form of the coin "nickel," where it is alloyed with copper, and in that of "nickel-plate," a coating given to steel which resists tarnishing. German-silver is a compound of copper, zinc, and nickel. Most of the metal of commerce is obtained from nickel-bearing magnetic and copper pyrites, — as, for example, in the important mines of Lancaster Gap, Penn., — and from a silicate of magnesia and nickel, known as *Garnierite*. The latter forms the chief source of supply in the mining districts of New Caledonia. An exceedingly attractive mineral, conspicuous at times by the extreme delicacy of its needle-crystals, is the sulphur ore of nickel, *Millerite;* it also occurs in fibrous crusts. Nickel is almost invariably associated as an alloy in the iron of meteorites. A new industry to which nickel has been applied is that of the manufacture of nickel-steel, an alloy of steel with about four per cent of nickel, used in the construction of armor-plating for vessels.

Iron, through its vast application in the arts, its easy and varied manipulation, and the facility with which it can be obtained in quantity, is to man the most important of metals. There is hardly a region of any extent where it does not occur in one form or another, and there are some regions which yield it in vast quantity. Even in rock-masses, where its existence is not made directly known to the observer by the obtrusion of the mineral itself, in the form of crystal, mass, vein, or bed, its presence is, nevertheless, often attested sooner or later by the formation of iron-rust. The coatings of rust on marble buildings indicate the presence of iron within the substance of perhaps an apparently pure marble. So, too, the accumulation of iron scum on meadow-bogs is an indication that iron has been leached out from some of the neighboring rocks, and there deposited by water. Again, the various colors of rock-masses are in themselves largely the indicators of the presence of iron in those rocks, since, in by far the greater number of cases, the varied colors which they possess are merely those which have been given to them through iron combinations, usually iron oxides.

Iron occurs native almost exclusively in the extramundane meteorites, where it is usually associated with nickel, and in certain volcanic rocks (basalts) of Greenland, in which it is scattered about in grains and nodules. The great iron-stones of Ovifak and Cape York, Greenland, which were at one time thought to be meteorites, and show many of their characteristics, are seemingly of telluric or earth origin, having been forced to the surface through eruptive action. The iron of commerce is obtained exclusively from ores of the metal, and in by far the greater quantity from the oxygen ores, the oxides of iron (*Hematite*, *Limonite*, and *Magnetite*). The world's annual production of the metal now amounts to about fifty million or fifty-five million tons, of which the United States (followed closely by Great Britain) alone supplies about fifteen million tons.

The most important ore of iron is the red oxide, known as *Hematite*, which occurs in a variety of forms, from massive to fibrous, botryoidal, earthy, and scaly, some of which are at first sight difficult to recognize. It has a brownish-black, reddish, or black color; but its powder, or the streak that is put upon it by the scratch of a knife, is invariably red (blood-red; hence the name, hematite — blood-stone). Its hardness is such as barely to permit it, except where crumbling, to be incised by a knife-blade, and on the firmer polished forms no cut is possible; its specific gravity is slightly over 5. Some of the blacker forms have an exceedingly high polish, reflecting light as if from a mirror or speculum (specular iron); at other times the lustrous parts are exceedingly minute and scaly, and barely distinguishable from the mineral mica (micaceous iron). One of the earthy forms is the pigment red-ochre. The important iron deposits of the Lake Superior and Alabama regions, and of Iron Mountain, Missouri, are of hematite, and occur in regular stratified and inter-stratified beds. Some of it, indeed, in the Michigan region has replaced whole beds of limestone, taking the place of the lime by slow and steady substitution following solution. In the same way, some of the Appalachian irons have replaced the original materials of the fossil-bearing rocks, and have replaced the fossils themselves; we find the iron marked with impressions of shells, corals, encrinites, etc., forming a true "fossiliferous iron" (also known as Clinton ore).

Considerably less important than hematite, but yet very important in itself, is the yellow oxide ore, or *Limonite.* It has, in some of its forms, largely the appearance of the preceding, but it can generally be distinguished by its brown color and yellow streak and powder. It is largely a bog-deposit, hence "bog-iron ore," and is frequently, even as a used ore, in a crumbly or earthy condition; stalactitic and mammillary forms are not uncommon. Brown-ochre pigment is manufactured from one of its earths.

A third oxide ore of iron is *Magnetite*, which, as the name suggests, has the distinguishing quality of being magnetic, i.e., of being attracted by the magnet; one variety, known as lodestone, is a true magnet in itself. This important ore of iron occurs in large, one might almost say mountain, masses, as we find it in some parts of Pennsylvania (Cornwall Mines), and in the Champlain and Adirondack regions of the State of New York. A frequent, but less serviceable, form is that of octahedral crystals of both large and small size, disseminated through schists and other rocks; these are often found protruding from the surfaces of broken-off hand specimens, their hard points easily distinguishing them. Particles of magnetite are also abundantly disseminated through trap and other rocks, from which they are liberated through weathering, and are then scattered about in the waterways of streams. The black bands, which are so frequently noticed in the courses of roadside rills and rivulets, are largely a construction of magnetite particles. An iron ore much resembling magnetite, but with much feebler magnetic qualities, and having in its composition zinc and manganese in addition to iron, is *Franklinite*.

The iron known as "spathic iron" is obtained from the carbonate of that metal, forming the mineral species *Siderite*. It is extensively mined in some regions, but is a much less important ore than those that have already been mentioned. It occurs in yellow-brown rhombohedral crystals of only moderate density (less than 4), and effervesces when treated with mildly heated acids. The yellow and green chrome pigments are obtained from *Chromite*, or chromic iron.

One of the most familiar of all the ores of iron, but of no service for the extraction of the metal itself, is the sulphur ore, or *Pyrites*. The beautiful and highly lustrous crystals of this metal are known to almost every one who has worked for some time among the rocks; for they are of very broad distribution, and are likely to occur in almost any kind of rock — slate, limestone, quartz, lava, coal, etc. The crystals are cubes, or modifications of cubes, of a brass-yellow color, and ordinarily so hard as to completely resist the impression of a knife. This fact should readily distinguish it from gold, with which it is frequently confounded ("fool's gold") by over-zealous searchers after the noble metal. Its greater hardness and less deep coloring also serve to distinguish it from the other form of "fool's gold," copper pyrites. Iron pyrites sometimes contain within themselves a small quantity of gold (sufficient at times to warrant the expense of mining), which is obtained from the baser metal by smelting, or through a natural process of rotting. Almost the only service to which pyrites are put to-day in the arts is the making of sulphur and sulphuric acid.

Another sulphur ore of iron, the special characteristic of which is indicated in the name of "magnetic pyrites," is *Pyrrhotite*. Its reddish or bronze color readily serves to distinguish it from ordinary pyrites. The frequent association with it of nickel makes it one of the valuable ores of that metal.

Manganese, as a metal, in its ore associations and in general chemical behavior, is very much like iron. It does not occur free in nature, and is obtained principally from its two oxygen compounds, *Pyrolusite* and *Manganite*, more commonly the former. It is largely associated with iron, less frequently with zinc and silver; and in one form or another occurs in nearly all rocks, from sedimentary to eruptive, and virtually through all the geological periods. It is readily taken up in solution by water, and again precipitated by it, following closely the method of formation of bog-iron. To nearly every one it is familiar in the fern-like coatings or crystal forms known as "dendrites," which by the uninitiated are frequently mistaken for true (fossil) fern impressions; the presence of the metal is also often determinable through a deep brown or brown-black stain. The principal application of manganese in the arts is the alloying of it with iron (Spiegeleisen) to make steel. Pyrolusite is extensively used to color glass and pottery, and produces the various shades of violet, purple, brown, and black.

Mercury. — This remarkable and exceedingly useful metal is known to nearly everybody in its liquid form of quicksilver — the substance that fills the bulb and tube of mercurial thermometers, and the basin and tube of mercurial barometers. It is the only mineral, except ice, which remains liquid at ordinary temperatures; but while the former melts at 32° F., mercury remains liquid until the very low temperature of – 40° F. is reached. Native mercury is a rare metal, and where occurring it is generally in the form of minute globules scattered through the rocks. Nearly all the world's mercury is obtained from the sulphur ore of that metal, the cochineal-red mineral known as *Cinnabar*. This species can easily be recognized in the combination of its three most distinctive characters: red color (with scarlet streak where scratched), great weight, and marked softness, being easily cut with a knife. Its weight, which exceeds that of metallic iron, is especially noticeable, but it is far below the weight of the pure metal (13.6). Apart from its service in the construction of thermometers and barometers, mercury has a hardly less important use in the arts through its formation of *amalgams*, compounds of mercury with gold, silver, zinc, tin, etc. The "silvering" on the backs of mirrors is ordinarily an amalgam of mercury and tin. The "amalgamation process" of extracting gold and silver from rocks in which they are contained consists in washing or agitating the powdered rock with mercury, and of subsequently reducing the gold or silver amalgams that have thereby been formed through the simple application of heat; the mercury is driven off, and the gold and silver are left behind.

Mercury is variously used in medicines, but its active poisonous properties permit it to be dealt out only in minute doses; its best known pharmaceutical form is calomel. The beautiful pigment vermilion is manufactured from cinnabar. Mercury is mined in quantity almost exclusively at Almaden, in Spain; at Idria, in the Austrian crownland Carniola; and at New Almaden and New Idria in California. The great mine of Huancavelica, Peru, which between 1570 and 1790 yielded a product estimated to have had a value of $67,000,000, has been abandoned.

Platinum is usually classed with gold among the nobler metals, and owes its great value chiefly to the fact that it is not attacked by the ordinary acids, and requires an enormous temperature, about 3,200° F., to bring it to a state of fusion. As native platinum it is not pure, but contains a certain (sometimes large) admixture of iron and other metals (*Palladium*, *Rhodium*, etc.); as such it is usually found in flakes and nuggets in gold-bearing gravels, and most of it comes from the Ural Mountains in Russia. Pure platinum, as obtained through artificial process, has a weight considerably exceeding gold (21 to 22 times that of water). From the manufacture of crucibles and the making of tooth-fillings and attachments, the special use of platinum has developed in the direction of electric appliances (platinum wires of incandescent lamps, etc.).

Aluminium or Aluminum. — This metal has of recent years obtained deserved recognition as one of special usefulness in the arts, and primarily through the double quality that it possesses of extreme malleability and ductility, and its light weight. The pure metal, which is not found native, has a weight less than that of ordinary limestone or calcite, its specific gravity being rated at 2.5; hence, possessing as it does the necessary tensile strength, it is made exceedingly valuable in the construction of articles where light weight is considered a desideratum. Such articles are found in military and naval equipments, in surveying instruments, racing and other boats (even to steam-launches), field-glasses, etc.

Aluminium is moreover non-oxidizable, and readily lends itself as an alloy to iron, copper (aluminium bronze), etc. The chief source of the commercial aluminium is found to-day in the minerals *Cryolite* and *Beauxite*; but the metal finds its representation in the common earths, clays, shales, and muds by which we are almost everywhere surrounded, and in the feldspar and mica constituents of the granitic and schistose rocks. These are in the main silicates of alumina. Unfortunately, the association of the metal in these compounds is such as to debar profitable extraction with the methods that are now in use. The advance in the aluminium industry may be inferred from the circumstance that forty years ago the cost of the metal per pound was from $27 to $90, whereas at the present day it is considerably less than a dollar.

The oxide of aluminium constitutes the mineral corundum (the grosser forms of which are powdered up to make emery), which in certain of its varieties is known under the names of sapphire, ruby, Oriental amethyst, and Oriental topaz, gem-stones of very high value and beautiful appearance. Corundum is, next to diamond, the hardest of minerals.

Sulphur is in many ways a most important mineral, and in its combination with various metals (silver, lead, zinc, antimony, etc.), forming their sulphides, constitutes some of the most important ores of those metals. In its native condition it is a beautiful sulphur-yellow mineral species, occurring either massive or in crystals, at times in powder, easily cut by a knife, and freely burning, when heated, with a pale blue flame. It then disengages the suffocating sulphur gas which is known to all who still use sulphur matches. Sulphur is largely associated with gypsum deposits; but in most part it is found in the region of active or partially quiescent volcanoes, sometimes occupying positions with the extruded rocks of volcanoes, or forming large deposits in their craters (as we find it in Popocatepetl). Its use in the arts is largely the tipping of sulphur matches, the making of gunpowder (with charcoal and nitre), and the proper preparation of the rubber for gum-shoes. It is also extensively used in the manufacture of sulphuric acid, but of late years much of the sulphur that is used for this purpose is obtained from the yellow sulphur ore of iron (iron pyrites).

Graphite or **Plumbago** is familiar to every one in the form of the black "lead" of lead-pencils. It is a soft iron-black or steel-gray mineral, which occurs in massive or foliated forms in the older crystalline rocks, gneisses, and limestones; it can be easily cut with a knife, and its specific gravity is only a little above 2. One of its distinctive characteristics is to streak paper, making marks not wholly unlike those left by antimony-glance, galena, and the mineral species Molybdenite. Its light weight and distinctly greasy "feel" readily serve to distinguish the mineral. Its soapy character eminently serves to make it useful as a lubricator (when pulverized), and its resistance to great heat permits it to be used to great advantage in the making (with clay) of crucibles. Most of the commercial graphite is obtained from Siberia and other parts of Asia; it is extensively mined in Ticonderoga, N. Y., and large deposits have been reported from various parts of Canada and Newfoundland.

Rock Salt occurs in extensive beds in many parts of the world, and is the source of much of the salt supply of the world. It is one of the few minerals that readily dissolve in ordinary water and impart to it a distinct taste, and by this character it can be immediately recognized. It is almost as soft as gypsum, a mineral which it frequently resembles and with which it is largely associated, and like it is in part an oceanic precipitate, and in part a lake sediment, accumulating over the floor or along the borders of desiccating water-basins. As the chloride of sodium (salt) is the most largely distributed of the "salts" held in solution by the oceanic waters, it would appear only natural to find many of the ancient oceanic sediments charged with this substance; and this in reality is the case. It is for this reason that so many of the deep-seated springs (artesian waters, etc.) are salty when they come to the surface, some of them being true brines. On evaporation, these brines yield nearly pure salt — a condition that applies equally to the waters of salt lakes and ponds — and thereby constitute an important source of supply of the commercial article. Artificial brines are frequently produced by admitting water to the seat of the deep-seated rock-salt deposits and then pumping to the surface; the water of exhaust, being evaporated, yields a resulting salt. Rock salt has generally a vitreous lustre, and may be white, yellow, red, blue, or even black in color.

Gypsum can be recognized very readily among rocks by its moderate hardness, ranking immediately after soapstone, and being easily scratched by the finger-nail. In some of its massive forms it clearly resembles certain limestones; but the quality of softness immediately distinguishes it, as does its pearly or satiny ("satin spar") lustre. The variety known as *Selenite* (moonstone) is to a high degree transparent. A common form that is extensively used in the arts, permitting itself to be fashioned by almost any cutting tool, is alabaster. Gypsum is in composition a hydrous sulphate of lime. On heating, the water is rapidly driven off, and the mass then drops to powder. This is the well-known "plaster-of-paris," which, when again united in proper proportions with water, sets hard, and forms the substance which we recognize in plaster casts and in the hard finish of walls. The quality of "hardness" in spring-waters is largely due to the presence of gypsum in solution. Extensive beds of this mineral are found in many of the sedimentary deposits, and in some cases appear to be a direct oceanic deposit; at other times, it is a lake accumulation or precipitate, forming in those bodies of water where an excess of evaporation over outflow produces general saltness.

Coal. — There no longer exists a question as to the vegetable origin of coal. In many varieties of coal the woody fibre of arboraceous plants can clearly be made out; in others the mineralized bark is well preserved; and in still others the microscope plainly demonstrates the presence of millions of pollen-spores, so closely packed together as virtually to make up the mass of the coal itself. The fact that the rock is in such a large proportion pure carbon is in itself sufficiently suggestive of a vegetable origin; but as to the precise manner in which the plant-tissues were turned into coal, or the approximate conditions which governed the development and growth of these plants, considerable doubt still remains. Some coal is manifestly merely a transformation of the black muck of peat-bogs — a long continued accumulation of growing and decomposing fibres of two or more species of bog-mosses (*Hypnum* and *Sphagnum*), united with other vegetable substances, and perhaps a certain quantity of mud. In other forms of coal, such as the brown coal and lignite, woody masses may make up the principal part, and at times with so little alteration in their substance as plainly to show in the mineral their full cellular or fibrous structure. For the greater part of the true stone coals — anthracites and bituminous coals — it is probably safe to assume that they represent a vast accumulation of vegetable *débris*, which, by slow stages of smouldering decomposition and accretion, has acquired thickness and mass as the bottom covering of swamps and river estuaries. The black muck accumulating over the floor of the Great Dismal Swamp of Virginia and North Carolina, in the cypress tracts of Florida and Georgia, and in some portions of the estuarine tracts of the Mississippi and the Amazons, may be taken as the expression of coal formation at the present day.

The most extensive coal-beds of the world — those, for example, of the United States east of the Rocky Mountains, of Great Britain, and of continental Europe — belong to the Carboniferous era; but from that period of time to the present coal has been forming almost continuously in one region or another, and frequently not passing beyond a brown coal or lignitic stage. In the Rocky Mountain region there are extensive beds of the Cretaceous and Tertiary ages, and in California good coal is worked in the Tertiary deposits. The older coals occur in alternating beds of coal and shale ("underclay," "fire-clay," "roof-clay"), and sandstone, generally neither the one nor the other of great thickness; the coal itself may be in thin inch-seams, developing from 2 to 10 feet or more, and exceptionally attaining 20 or 30 feet in thickness. There may be as many as 50 or 100 layers of dead rock and coal alternating with one or another; and, indeed, in a few places as many as 200 and 250 such layers have been indicated. The alternating beds were largely the soil in which the coal-forming plants were rooted, but the fact that they frequently contain the remains of marine organisms (fossils) within themselves makes it evident that the sea frequently encroached within the coal-forming area. In other words, the swamps accumulating the coal were in direct communication with the sea, and their waters must necessarily have been in great measure salty. The main coal formation of the United States, extending from the Appalachians to far west of the Mississippi River, and from New England to Alabama, gives evidence of the former existence of a vast swamp or morass covering hundreds of thousands of square miles.

The plants of these older coals, although at times of giant proportions, belonged in the main to forms which to-day are perhaps most nearly represented by the lowly club-mosses and horse-tails; *Lepidodendron* and *Sigillaria* rose certainly 70 to 80 feet in height, with trunks 4 or 5 feet in diameter, and *Calamites* could in its full development hardly have been less than 40 feet. None of the modern type of trees, except possibly some conifers, were represented. The growth was a surpassingly luxuriant one, — tropical, one might say, in its density, — but it gives little indication as to the temperature or climate under which it flourished. The luxuriance of the forest which to-day extends to the glacial lands of Alaska is a lesson that enforces caution in dealing with a question of this kind.

Coal in its different forms presents us with a large range in the proportion of carbon which it contains. In the best anthracite the carbon may be present to the extent of 90 or 95 per cent; in the better bituminous varieties it usually makes up from 65 to 75 per cent; in the brown coals it may be anywhere from 30 to 50 per cent; and in peat it is not infrequently reduced to one-half of this amount, or even considerably less. The impurities are various volatile matters, water, and greater or less quantities of mineral ash. Anthracite appears to be in most cases a transformation from bituminous coal through heat and pressure, conditions brought about by rock-movements or through volcanic contacts. The anthracites of the world — those of the Appalachian basin, for example — are mainly in regions of great disturbance, and they pass off gradually into the less highly carbonized coals that occupy the contiguous areas of little disturbance.

It is assumed that there may be in this country about 300,000 square miles of coal-bearing strata, of which the Appalachian district, extending from Pennsylvania to Alabama, comprises some 65,000 square miles, the central area (Indiana, Illinois, and Kentucky) somewhat less than 50,000 square miles, and the western area (from Iowa to the Rio Grande) about 100,000 square miles. Of all this vast area, however, hardly a fifth is at this time worked or coal-producing, the condition of the coal being such as not to permit it to be mined with profit. Nearly all the anthracite of this country is obtained from the anthracite fields of Pennsylvania, and from the three regions which are generally designated the Wyoming, Lehigh, and Schuylkill. The output of coal in the United States amounted, in the year 1895, to 194,000,000 (short) tons, of which the Appalachian anthracite fields furnished upwards of 58,000,000 tons, and the State of Pennsylvania alone (in anthracite only) 51,700,000 tons. In 1895 the combined anthracite and bituminous output of Pennsylvania amounted to 110,000,000 tons. Great Britain (with 188,000,000 full tons in 1891) is still the largest coal-producer, and is then followed by the United States and Germany (94,000,000 tons).

Petroleum ; Natural Gas. — These are products, seemingly, of some kind of natural distillation of organic remains — remains most often, probably, exclusively vegetable, at other times animal and vegetable, and less frequently only animal. At least, so close is the resemblance between these substances and certain products (oils and gases) obtained by artificial distillation from organic bodies, that such reference is made reasonable, and it does no violence to any facts that are known to us. The source of both petroleum and natural gas is found mainly in the deposits of Paleozoic age, from the Lower Silurian to the Carboniferous; but in many regions they are obtained from deposits of much newer date. Sandstones and conglomerates are most highly charged; but some shales, clays, and limestones are not entirely deficient. It was formerly supposed that both petroleum and natural gas (which is largely marsh gas) stood in bonded relationship with the coal deposits, — from which it was assumed they were obtained through a process of destructive distillation; but the fact that both are so largely associated with rocks of much older date than the coal makes this view untenable, or at least very doubtful. Both petroleum and natural gas show rapid exhaust, a proof that they are local accumulations, and do not replenish — at least, not in a short period — as do the natural waters. The production of petroleum in the United States amounted to, in 1893, 48,000,000 barrels, of which New York and Pennsylvania combined furnished 20,000,000 barrels, and Ohio 16,000,000.

The production of natural gas in this country in 1893 had a valuation of some $14,000,000, of which Pennsylvania furnished about one-half. In 1888 this State reached a maximum output, valued at $19,000,000, which was followed by a rapid decline, due mainly to an exhaust from the worked areas. The issuance of this gas from certain wells is simply prodigious, the production ranging as high as several millions of cubic feet per day; but a rapid outflow is almost invariably accompanied by a steady, sometimes by a very rapid, decline.

The substance known as *bitumen*, or *asphaltum*, can properly be noticed in this connection. It, too, seems to be a distillation product derived from organic bodies, and possibly it represents a stage of alteration removed one step beyond petroleum. A very large, and perhaps the main, source of supply of this substance is the famous pitch lake of the island of Trinidad.

CHAPTER XVIII.

BUILDING-STONES, SOILS, AND FERTILIZERS.

Building-Stones. — Under this head may properly be included not only the materials that are directly used in construction, but such as lend themselves to ornamentation, to design, to flagging, and to other related purposes. These are the granites and their allies, sandstones, limestones and marbles, shales, and slates, all of which, in their geological aspects, have been discussed in Chapter II. Numerous considerations determine the possibility of using stone in construction. The matter of expense in quarrying, the facility or difficulty of transportation, proper coloring, consistency of grain, hardness, resistance to crushing strain and chemical decomposition, etc., — all have to be considered; and it is rarely that all the desired conditions are satisfied in any one construction. For general purposes the rocks of a given region, even if of inferior or undesired quality, are used in the neighborhood by preference over superior rocks of a more distant locality, as the question of transportation is at once eliminated from the burden of delivery; and in truth it must be said that there is hardly a region of granites, of sandstone, or of limestone, which does not yield a fairly good quality of building or monumental stone. Naturally, where special features are desired, or where superior strength is a real necessity, as in the construction of massive buildings and in piers and railroad abutments, selection becomes imperative; but even the most careful selection is at times only sealed misjudgment, as the factor of chemical decay cannot always be determined in advance. Oftentimes, too, the manner of placing a block in construction will have much to do with its retaining power; regard should be had to the protection of the original bedding-planes, for it is along these that the destructive water is apt to enter, and, in both chemical and physical ways, begin the work of disruption. The heat of the sun, combined with the cold of night, forcing alternate expansion and contraction of the rock, is also a disrupting agent; and the amount of bad work done by it will in great measure depend upon the extent of continuous surface that is exposed to its influence, and the character of the rock-face that it acts upon. The "peeling" of sandstones would largely be prevented were proper regard had to the original laying of the blocks.

Granites of a homogeneous and moderately fine grain are preferable to those in which the component elements are largely irregular in size, and make up a distinctly coarse texture. The Cape Ann, Quincy, Aberdeen, and Richmond granites have long been considered types of good granites; but many other regions afford equally good and serviceable stone. Many stones commercially sold as granites are, however, not true granites; and some of them are not even closely related to them. Such are the various traps and diorites ("greenstones") of volcanic origin — the dike material of some of our hills and mountains — which are extensively used in road-paving. Thus, much of the "Belgian granite blocks" of our city streets is derived from the mass of the Hudson River Palisades, or from other igneous extrusions. Some of this rock is fully as resisting as granite, and is therefore allowed to meet (although not by legal recognition) a granite specification. The rock known as Syenite, which is wholly or almost entirely deficient in quartz, and in which a black hornblende replaces the mica of true granites, is but little inferior to the best of building-stones.

Granite, lacking the divisional planes of stratification, would ordinarily present insuperable difficulties to quarrying, were it not for a series of joint planes, or "lines of jointing," which usually traverse the mass in three or more directions, and divide it up into quadrangular or dome-shaped blocks of greater or less dimensions. These lines of separation, which are present in greater or less degree also in sandstones, limestones, etc., are largely due to contraction on cooling from a heated condition, and in other part to dislocations which the rock has undergone through squeezing and folding. When the joints follow one another very closely, the granite may be so completely cut up as to render it unfit for quarrying purposes; at other times, hundreds of feet may intervene between the nearest joints. Another series of traversing lines, which are more of a microscopic character, and give evidence of weakness by a tendency of the rock to split with smooth fracture planes, are known as "rifts."

Sandstones are ordinarily good building-stones, but their resistance to crushing is very much below that of granite; on the other hand, the fact that, at least in the better varieties, the rock is made up in much the greater part of pure quartz grains which repel the action of solvents, makes it exceedingly resisting to chemical disintegration. This is especially the case when the binding cement is also siliceous; but it is much less so when this is lime, which readily "eats out," and leaves disagreeable holes and cracks, a proper preparation for full disintegration. The readiness with which certain sandstones absorb and retain water, which by expansion in freezing can easily disrupt the mass, emphasizes caution as to the proper selection of the required variety of the stone, and its proper placing in construction. The unsightly scars brought about by "shaling" or "peeling" of the surface are familiar disfigurements of even stately mansions. In the Eastern United States, especially in large cities like New York, Brooklyn, Boston, and Philadelphia, the sandstone used most largely in house construction is the well-known "brownstone" ("new red sandstone" of geologists) of the brownstone fronts, obtained from the Triassic deposits of Pennsylvania, New Jersey, and Connecticut. The central States of the Union, more particularly Ohio, furnish an excellent gray or cream variety (Berea stone, etc.), which much resembles the famous Fontainebleau stone of France (the material of construction of the Paris houses).

Limestones and marbles, when of good quality, also make good building-stones; and while it is true that they readily lend themselves to the solvent action of the carbonated waters of the atmosphere, the dissolution is so slow a process, and takes place so evenly when the substance acted upon is largely pure, that little regard is had for this condition. Hence it is that some of the most massive buildings of the world are constructed of marble. The facility with which marble is quarried, the rock being marked off by separating planes of bedding, and transversely parted by even and regular lines of jointing, and the readiness with which it can be fashioned by the cutting-tool, are important elements tending to popularity in favor of this stone. At the same time its light color, assuming it to be white, rapidly defaces through the streaks of iron-rust which sooner or later appear on its surface, the evidence of iron oxidation taking place in the interior. Many parts of the United States furnish good quality limestones and marbles, among the better known of which are the Rutland marbles of Vermont, the Joliet stone of Illinois, and the Dayton stone of Ohio.

It is well known that marble is used for various other purposes besides main construction, in window and door facings, interior decorations, etc. Colored varieties are frequently selected for interior work; and as marble occurs in almost all shades from white, through yellow, blue, and red, to black, no difficulty is met in securing a choice of design. Some of the fossiliferous varieties make handsome decorative slabs for mantels, table-tops, etc., the polished surfaces showing beautifully the fossil forms that so largely make up the rock. The so-called Tennessee marble is a limestone highly charged with organic fragments. For statuary purposes the Italian (Carrara) marble is still preferred, owing to the peculiar tough-crystalline structure which distinguishes it, and which does not permit it to crumble before the blow of the chisel and mallet.

Flagging-Stones are most commonly large slabs of either shale or shaly sandstones, and less often limestones. In selecting these materials little regard is had for any condition beyond extent of surface and freedom from knotty impurities; the latter, if present and of real hardness, weathering or wearing out into disagreeable prominences. The ripples, which were originally implanted in the rock at the time of its making, frequently show up well after the paving has been used for some time, and give to the surface of the stone a wavy or undulating appearance, which the geological student will not be long to recognize. Much of our flagging-stones is known under the name of "blue-stone," and is obtained from the almost inexhaustible deposits of the Silurian and Middle Devonian ages. Limestone and granite flag-pavings are apt to become "gummy" when washed over with water and mud, and slippery when coated with snow, and are, therefore, in a measure objectionable. Latterly, the introduction of asphalt and "artificial-stone" pavements has made considerable headway, and is likely to receive increased favor in the future.

Roofing-Slates and Tile-Stones occur in a variety of forms; but their principal differences relate only to size, thickness, and color (red, blue, green, black). It is true that the composition varies considerably, depending largely upon the presence or absence of a certain quantity of lime; but in general the economics of the rock depend almost entirely upon the regularity of surface that is obtainable, and the facility with which it separates into thin leaves. Many geologists apply the term "tile" or "tile-stone" to the shales of thin bedding, and recognize as slates only such aluminous rocks as break off or "cleave" into thin plates more or less transverse to the planes of true bedding. This form of transverse breakage or cleavage seems to have been brought about as the result of hard tangential pressure of the rock, and at times coincident with mountain-folding. Hence it is that slates of this character are found almost exclusively in regions of great disturbance, or where volcanic extrusions have reacted with violent force upon the rock-walls which formed the boundaries of their passage toward the surface. Lavas themselves are not infrequently cleaved into slates.

Clays and Soils are in many cases so intimately bound in with the special rock-formation of a given region that it takes no keen eye to determine that they are merely a derivative product, obtained by direct destruction from the rock-masses immediately adjacent. The red dust and muds overlying decomposing red shales and sandstones, the white dust and sands associated with regions of light-colored sandstones, the sparkling micaceous particles that are found in the soils of granitic regions, etc., clearly point out this fact. But there are vast areas where a good deal of the soil is a stranger to the place where it is found, having been brought thither from possibly distant regions. Such is the condition of the regions that still lie deeply buried beneath the "glacial drift," — the vast accumulation of bowlders, gravel, and clay which was associated with the steady advance over the country of the giant glaciers of the Great Ice Age or Glacial Period. Geologists speak of the various forms of these deposits as "bowlder clays," "till," "drift," and "brick clays" (the best bricks being made from the exceedingly fine and largely homogeneous clays of the drift). In some regions, on the other hand, as in parts of Canada and Labrador, there is little or no soil, whatever existed at one time having been scoured away from the rock supporting it by the trespass of glacial ice.

Soils have varying characteristics, and adapt themselves in different ways to the necessities of plant-life. Some are stiff, holding water on the surface (and barely permitting it to penetrate), while others are loose, and allow water to pass as if through a sieve; a medium condition is that which is ordinarily best suited to agricultural purposes. Excessive ploughing may tend to excessive loosening, a condition which is also materially favored by the operations of the earth-inhabiting animals, such as the ants, earthworms, and even moles. The presence of clay-beds tends to check water-penetration, as does likewise a close vegetable growth on the surface. Sandy clay soils are known as "loams," and limy ones as "marls;" but under the name of marl, especially in the Atlantic border region of the United States, is frequently included a series of earthy deposits which in fact have little relationship with true marl, and of which an essential ingredient is the greenish silicate of iron or glauconite; hence the deposits are also known as "greensands."

The fact that there are rock-beds that are pervious, and others that are all but impervious, to water, permits us to locate the position of the water-bearing series — in other words, to determine the approximate level to which the water may have penetrated (through sandstones, limestones, etc.), and where it is now held up by the largely impenetrable clays. This is an important consideration in the location of artesian tappings; as it determines in advance the amount of work that will be required to obtain the needed water-supply, and the probable expenditure that such work would entail.

Fertilizers; Lime, Guano, Phosphates. — The presence of the salts of lime, potassium, and sodium is a condition of the soil that meets the requirements of plant-growth; and without them, either in part or in whole, the soil becomes fallow. It is then that fertilizers are needed to restore the life-giving properties that have been removed from it. The restoratives most generally in use, other than animal and vegetable manures, are lime (burnt from limestones), gypsum ("land plaster"), and various forms of lime-phosphates, together with the green glauconitic marls to which reference has already been made. The lime-phosphate, constituting the mineral species Apatite, which is measurably abundant in the older rocks of Canada, has a moderate use as a fertilizer; but it is far surpassed by the regular rock phosphates, which, in nodular and irregular masses, characterize many of the limestone deposits of the Southern United States, in Florida, Alabama, and North and South Carolina. These phosphates, which still harbor in quantity, in the shape of teeth, bones, etc., the remains of formerly existing animals, have unquestionably been formed through the agency of animal decomposition — the union with the lime of the liberated phosphoric acid. In some places the animal accumulations make true "bone-beds," and as such are admirably adapted to soil-fertilization.

Most of the more important phosphate deposits belong to the Tertiary period of time. In certain districts the limestones are in themselves sufficiently charged with phosphatic material to constitute good plant-food.

The excrement of various forms of marine birds, known under the name of guano, was formerly (and still is to-day, to some extent) an important source of phosphatic supply; the most extensive beds were those of the Chincha Islands, off the coast of Peru.

CHAPTER XIX.

SOME OF THE COMMONER ROCK-FORMING MINERALS, AND MINERALS OCCURRING IN ROCKS.

Quartz, rock-crystal, or silica is the commonest of all minerals, and can generally be recognized by its glassy appearance and extreme hardness, ranking as 7 in the *scale of hardness* which is generally recognized by mineralogists:—

Talc or Soapstone . . .	1	Feldspar	6
Gypsum (or Rock-salt) .	2	Quartz	7
Calcite or Spar	3	Topaz	8
Fluor-Spar	4	Corundum	9
Apatite	5	Diamond	10

It is the substance of most sea-shore sands, the material of sandstones, and one of the three essential constituents of typical granite and gneiss. In chemical composition it is a union of the elements oxygen and silicon. It occurs in undefined or *amorphous* masses or particles, and commonly in more or less perfect six-sided (hexagonal) prismatic or pyramidal crystals. A knife-blade will not cut it, while it in itself readily scratches glass; and when broken across, the fracture-surfaces are almost invariably irregular and rounded (conchoidal).

Quartz occurs in a great variety of form and color; and among the commoner types, as determined by col-

Plate 62.

SOME FORMS OF CRYSTALS.

The mineral species are named from left to right for each of the four rows:—

1. Quartz (hexagonal prism). 2. Zircon. 3. Fluorite (octahedron). 4. Garnet (trapezohedron).
5. Quartz (modified hexagonal prism). 6. Rock-Salt (cube).
7. Gypsum. 8. Quartz. 9. Calcite (rhombohedron).
10. Emerald (hexagonal prism). 11. Gypsum. 12. Topaz. 13. Staurolite (intercrossing-twin).

oration, we recognize black- or smoky-quartz, rose-quartz, yellow- or citron-quartz, white- or milk-quartz, and the transparent crystalline rock-crystal; the last named is the Rhine-stone, "Cape May Diamond," "Lake George Diamond," etc., of commerce. More highly prized or less common varieties are: *Amethyst*, a fine purple kind; *Carnelian*, a red variety with a waxy lustre; *Opal*, an opalescent form, showing frequently a beautiful play of colors; *Chalcedony*, a more or less translucent or transparent variety of a dull color and with a certain waxy lustre; *Agate*, a variegated Chalcedony, with the colors arranged in distinct bands; *Onyx*, very much like Agate, with usually white and black (or brown) bands arranged in even planes; *Sardonyx*, like Onyx, but with red bands in association with the white or black; *Chrysoprase*, an apple-green Chalcedony; *Heliotrope* or "Blood-stone," a dark green variety with scattered spots of red; *Jasper*, an opaque variety of a green, brown, or red color, frequently banded in color; *Flint*, an opaque, dull quartz, usually of a dark or nearly black color; *Chert* or Horn-stone, an impure, brittle flint, more commonly of a grayish or brownish color; *Lydian-stone* or touchstone, a velvet-black, flinty form, frequently used for testing the purity of metals; and *Cat's-Eye* (this name is, however, applied to other minerals).

Quartz or silica is, again, the substance of silicified trees, or, in the form of opal, of wood-opal, which is much the same thing.

Calcite, or as it is frequently, but not very correctly, termed "spar," is, after quartz, the most common of mineral species. It likewise occurs in massive and in crystalline forms; as the first, it is the substance of shell, limestone, marble, and chalk, and of the cave-deposits known as stalagmites, stalactites, and stalactitic crusts (Mexican "onyx," etc.). Its various crystalline forms (in rhombohedrons, scalenohedrons) are ordinary *calc-spar*, *nail-head-spar*, *dog-tooth-spar*, and *Iceland-spar* (a beautiful transparent variety).

Calcite occurs in a great variety of color, ranging from white through yellow, green, blue, pink, and black. In its truly crystalline forms it has the glassy appearance of quartz; but it can be readily distinguished by the facility with which it is cut by a knife-blade, and its characteristic of undergoing rapid solution in almost any acid, with a *free liberation of bubbles of carbonic acid gas*. This property of *effervescing* belongs to nearly all carbonates, the carbonic acid of their composition being driven off or liberated by the stronger acid. Calcite is chemically a compound of carbonic acid and lime (a carbonate of lime).

A mineral *Aragonite*, closely related to calcite, and having its chemical composition, should be mentioned here; also a second, *Dolomite* or *pearl-spar*, which is a double carbonate of lime and magnesia. Many of the giant limestone mountains of the world, such as the famous Dolomites of the Tyrol, are made up in greater part of this mineral, as are likewise some of the finest statuary marbles.

Feldspar is, after quartz and calcite, the most abundant and important of rock-forming minerals. It is one of the essential constituents of granite and the granitic rocks, also of the gneisses, and is the substance which generally imparts the distinctive coloring to those rocks; thus, red or flesh-colored granite is largely constructed of pink or reddish feldspar, green granite of green or greenish feldspar, etc. It can easily be distinguished in most cases from the quartz with which it is associated in these rocks by its color — the quartz being almost invariably gray — pearly (not glassy) lustre, and by its breakage-surfaces, which are generally flat, and not irregularly curved or granular. It is also somewhat less hard than quartz, and can at times be indented with a knife.

In composition feldspar does not differ very greatly from ordinary earth or clay; indeed, it is from the decomposition of feldspars that much of the material of soil is obtained. Porcelain-earth, or *Kaolin*, is also a product of its decomposition. It is a compound of silica and alumina (silicate of alumina), with potash, soda, or lime added to these substances. The most common form of feldspar, and that which is found most generally in granitic rocks, is the potash-feldspar, or *Orthoclase;* its hardness alone will suffice to distinguish it from calcite, which it sometimes closely resembles. Of its varieties are the clear and glassy forms known as *Adularia* and *Sanidine;* also the somewhat opalescent *moonstone*. The beautiful blue-green feldspar found near Pike's Peak, Colo., and in Liberia, known as *Amazon-stone*, has the composition of orthoclase.

A not uncommon feldspar is that containing soda, and known as *Albite*, from its common coloring. Of the feldspars containing lime and soda should be mentioned *Oligoclase* and *Labradorite*, the latter often showing a beautiful play of color, with peacock-blue as its base.

Apart from their ordinary occurrence as essential components of granitic rocks, feldspars often unite with quartz to make veins and dikes penetrating the granitic rocks, sometimes in exceedingly coarse form, with the feldspar developing into massive crystals. These crystals not infrequently measure a foot, or even considerably more, across.

Mica is an important rock constituent, as it is one of the parts of typical granites and gneisses, and the most distinctive part of the vast system of rocks which bear the name of mica-schists. It is distinguished from all minerals by its very perfect cleavage, which permits it to be split up into exceedingly thin sheets or leaves. These are used for various purposes, one of the most common being the "glazing" of stove-doors (as such incorrectly called "isinglass"); in some regions the larger plates are also used for windows. In the commoner forms of micaceous rocks, it occurs generally in small scales or in more or less perfect crystalline forms of from a half-inch to an inch in diameter; but in certain regions, as where the mineral is commercially mined, plates are not infrequently removed which measure two, or even three, feet.

The micas are essentially silicates of alumina, with potash, magnesia, and iron, and more rarely soda, added. The commonest variety, and that which is used commercially, is the potash-mica, or *Muscovite*, ordinarily called white mica. It is the silver-white variety, at times completely transparent, even in thicknesses of many layers: but, again, it shows a tendency to smoky color; and when this is well emphasized, especially in many thicknesses, it passes off in the direction of the next species, *Biotite*, the so-called black (also deep green) mica, a magnesia-iron form. Modifications of this species are the brown or coppery-red *Phlogopite*, and the singular star-mica, the latter showing a clear six-rayed star when a candle-flame is viewed through it. An interesting lilac or pink mica is *Lepidolite*, in which lithia is the accessory mineral; *Margarite*, or pearl-mica, as the second name clearly implies, has a distinct pearly lustre on its cleavage surface.

Hornblende, or Amphibole, which is a common accessory mineral in granites and gneisses, forming hornblendic granites, etc., can generally be recognized by its hardness, lustre, and dark, black or almost black, color. In small scales or flakes, it much resembles black mica, and is often mistaken for it by the young mineralogist; but it does not flake off like that mineral, nor can it be cut easily (if at all) by a knife. It is essentially a compound of silica, magnesia, and alumina (a silicate of magnesia, with alumina). Sometimes it is so abundant as to build up a solid rock by itself, hornblende rock; or, where alternated off with particles of another mineral species, as quartz, hornblende schist. It has a hardness of 5–6, and a vitreous or pearly lustre.

Nearly related to hornblende are *Actinolite*, a beautiful green or greenish mineral, often occurring in fibrous or radiated masses; *Asbestus*, a very fibrous white or gray mineral (silicate of magnesia and lime), which is at times woven into an incombustible paper or cloth; and *Mountain-leather*, an asbestus-like substance occurring in tough sheets of interlaced fibres.

Pyroxene, likewise a silicate of magnesia, with lime, alumina, or iron added, has much the habit of hornblende; and like it, it has a variety of associations. Its hardness is rated at 5.5 to 6; it also has a vitreous lustre, and in color varies from gray to green and black. One of the commonest and most important varieties of this mineral is the black or greenish-black *Augite*, which enters so largely into the composition of some of the volcanic rocks, as trap (basalt, diorite, greenstone). Minerals related to pyroxene, or forming varieties of it, are *Diallage*, a foliated mineral of a green color; *Enstatite*, which by decomposition seems to yield talc or soapstone; *Hypersthene*, a silicate of magnesia with considerable iron, and at times with an almost metallic lustre; and *Bronzite*, a ferrous variety of enstatite.

Garnet is one of the commonest and most abundant of the accessory minerals contained in rock-masses. Its usual association is with granites, gneisses, and mica-schists, especially the last two, in which it occurs in well-defined crystals of (commonly) twelve or twenty-four sides (dodecahedron, trapezohedron), and of sizes varying from a pin's head to three-quarters of an inch or more; some of the Colorado garnet crystals measure three inches across, and weigh from three to five pounds. The gneisses and mica-schists are sometimes so full of this mineral as to appear completely peppered by it, and the latter is virtually converted into a garnet-schist. Again, garnet itself sometimes occurs massive, so as to make a distinct garnet-rock. In composition it is essentially a silicate of alumina, with additions of lime, magnesia, iron, and manganese; hardness 7 to 7.5, therefore greater than that of quartz or rock-crystal.

Garnet, in its most common form of a red crystal, can easily be recognized by its ordinary garnet appearance; i.e., by its resemblance to the stone of commerce, which it is, in fact. The so-called "precious" garnets are merely the clearer varieties which permit of cutting for gem-stone. They are generally of the varieties known as *Pyrope* (a magnesia garnet) and *Almandite* (an iron garnet); the *Hessonite*, or "cinnamon-stone" (a lime garnet), is also used for commercial purposes. Among the other forms and varieties that may be mentioned are *Grossularite*, a lime garnet of yellowish or greenish (sometimes brown or rose) color, so-called from an assumed resemblance to the gooseberry; and *Uvarovite*, a chrome garnet of a beautiful emerald-green color; the common forms of gneiss and schist are the iron garnets, *Almandite* and *Andradite.*

Tourmaline is a common accessory mineral in granites and associated rocks, but it also occurs in limestones and arenaceous rocks. Its usual form is that of a glassy prismatic crystal, with three, six, or nine sides (or rounded in such a way as to obscure the sides), of coal blackness, and with a powdery fracture, much like that of coal. The crystals are at times hardly larger than hair-lines, and are then frequently grouped in radial clusters; at other times they are of almost ponderous proportions, rivalling some of the largest known. It frequently so nearly resembles hornblende as to be easily mistaken for it; but the absence of cleavage, the brittle, coaly fracture, and glassy form of the mineral ought to serve to distinguish it. In quartz masses, where it so often occurs, it frequently shows itself to be traversed by quartz veins or partitions, looking as though it were patched up of superimposed parts. In chemical composition it is essentially a silicate of alumina, with iron, magnesia, and the rare element boron; lithia, soda, or potash may also be present. The hardness is 7–7.5. Tourmaline, apart from its more common black form, occurs in brown, green, yellow, blue, and pink, and sometimes in combinations of green and pink; the pink variety, known as *Rubellite*, contains lithia.

Fluorite, or Fluor-Spar, a compound of calcium and fluorine, is one of the most beautiful of minerals; and its cubical crystals of yellow, green, blue, purple, red, and brown — also colorless — can easily be distinguished either by form or moderate hardness, 4, from those of calcite and quartz. It also occurs massive, like calcite, and in one of its ornamental forms constitutes the beautiful Derbyshire spar. Fluorite possesses the property known as *fluorescence*, — emitting a peculiar blue light of its own, — and when fragmented and moderately heated becomes phosphorescent. Hydrofluoric acid, which is so extensively used in the arts for etching glass, is obtained from it.

Apatite, a compound of phosphoric acid and lime (phosphate of lime), is a widely distributed mineral, and is eagerly sought after for its beautiful hexagonal crystals of yellow, green, blue, red, brown, and black; some of these are quite clear and colorless, but ordinarily they are opaque, and with glassy or resinous lustre. Exceptionally, as in parts of Canada, the crystals may be as large as a nail-keg. The hardness is 5, and therefore below both feldspar and quartz. It is largely associated with the crystalline rocks, where, either in its crystalline form or as amorphous masses, it fills in veins, streaks, and pockets. It has been extensively mined for the fertilizing phosphate which it yields under proper treatment; and from it also is obtained some of the phosphorus of commerce.

Beryl is not a rare accessory component of the granitic rocks. It occurs usually in hexagonal crystals, abruptly terminated or truncated, of a green color, some of them very much resembling the more glassy forms of green apatite, and at times difficult to distinguish from them. The hardness is, however, above that of quartz, 7.5. As with apatite, the crystals are often of ponderous proportions, some of the New Hampshire specimens being as large as a barrel. The clear and transparent varieties of beryl are among the most highly prized of gem-stones; such are *Aquamarine*, of a clear mountain-green color, and *Emerald*, of a deep emerald-green. Yellow and pink varieties are also known. Beryl is in composition a silicate of alumina and glucina; the element glucinum, or beryllium, in combination with aluminic acid, forms the gem minerals *Chrysoberyl* (with the variety known as "cat's-eye") and *Alexandrite*.

Topaz is ordinarily considered one of the gem-stones; and, like most of these, its association is with the crystalline rocks, granites, and gneisses. It occurs in prismatic crystals, frequently of large size, and colorless, or of shades of white, yellow, blue, and pink. Most of the pink coloring seen in these stones has been artificially brought about. Topaz is one of the hardest of minerals, rating as 8; but it breaks readily in a direction across the crystal prism. In composition it is a compound of silica and alumina (silicate of alumina), with the rare element fluorine added.

Cryolite is a rare mineral, occurring in quantity only in South Greenland; but it has come into prominence through its association with the making of soda salts and the extraction of the much-coveted aluminium metal. It is an attractive white (sometimes reddish) mineral, and receives its name cryolite, or ice-stone, from an assumed resemblance between it and blocks of ice; it fuses readily, and in thin pieces will burn even in a candle-flame. In composition it is fluorine, sodium, and aluminium.

Turquoise is readily distinguished as a gem-stone by its robin's-egg-blue color.

It occurs only in massive form (not in crystals), filling cavities and seams in volcanic rock; the best forms come from Persia and New Mexico. It is a watery or hydrous compound of phosphoric acid and aluminium (phosphate of alumina).

Ruby, as the gem-stone, is an oxide of aluminium, and properly only a variety of the mineral corundum; as such, it should be distinguished from Balas-ruby, or *Spinel*, which is an aluminate of magnesia. As has already been described under corundum, the bright blue variety is known as *Sapphire*, the purple as *Oriental Amethyst*, and the yellow as *Oriental Topaz.* The finest true rubies still come from the Orient, — Siam, Burmah, and elsewhere in the East Indies, — and the sapphires from Ceylon. These all have a hardness next to diamond, 9, and consequently stand second in the scale of greatest hardness.

Diamond usually occurs in the form of small octahedral crystals, but sometimes, as in the case of the famous crown diamonds, as large as a robin-egg, or even considerably larger. Its distinctive qualities — such as brilliancy, extreme hardness, infusibility, and insolubility — are well known; when highly heated, it slowly consumes, and disappears as carbonic acid gas. In composition it is pure carbon. Its most highly prized varieties are colorless and clear as water (hence, "of the first water"); but gems are not uncommon in pale shades of yellow, green, pink, and blue. The famous "Hope" diamond has a decided blue color; less valuable as gem-stones — in fact, scarcely valuable except as curiosities — are the black diamonds. Much of the impure dark variety (known as *Carbonado*), and the fragmental pieces that are not serviceable for gem-stones, are used in the form of diamond powder (*bort*) for polishing and cutting purposes (diamond-drilling).

The most important diamond-producing countries of the world are India, Brazil, and South Africa; at the present time, South Africa far surpasses in output the combined outputs of all the other regions of the earth's surface. Several tons of the precious stone have actually been obtained from the Kimberley mines, along the Vaal River, during the period of the last quarter of a century. The diamond is commonly found in gravel deposits, or in rocks formed of their consolidation, and in a peculiar blue earth or blue rock known as Kimberleyite, or modified Peridotite; little is known as to its origin or genesis. Among the most famous stones are the "Koh-i-noor" of the English crown jewels, the "Orlov" of Russia, the "Florentine" of Austria, and the "Regent," or "Pitt," now in the Louvre of Paris. All of these have been far surpassed in size by recent finds in the Orange Free State, South Africa.

TEACHERS' REFERENCES.

CHAPTER I. — State the general changes which rock-masses undergo; the effect of water-freezing; the influence of temperature alternations. Define the nature of internal disintegration. Give the two distinctive methods of rock-destruction. What is understood by "weathering"? State how desert sands are formed, and give the reason for their accumulation in great quantity. Indicate the general course which the materials resulting from terrestrial destruction take, and note their special distribution.

CHAPTER II. — Define a sandstone, a conglomerate, and indicate whence the materials of their construction have been obtained. What is the nature of a binding cement? Describe accurately a limestone, and enumerate a few typical forms of such rock; give its chemical and its organic structure. How does marble differ from ordinary limestone? What is coquina? Give the composition of chalk, and indicate its relations to the oceanic or Globigerina ooze; define the latter.

Define flags, shales, and slates; indicate their points of agreement and of difference, and point out their relations to modern mud and soil. What special marks have been impressed upon them? — ripples, raindrop impressions, etc. Give the construction and composition of granite and syenite, indicating the mineral constituents of each. Enumerate some varieties of granite and granitic rocks. State the origin of granite. Give a broad classification of the rocks of the earth, defining the terms igneous, aqueous, and plutonic. Describe gneiss, and point out some of the characters wherein it agrees with, and differs from granite. What is understood by "foliation"? State the origin of gneiss, and give an explanation of the terms "metamorphic" and "metamorphism." Describe the term "schist," and enumerate some of the schistose rocks, — mica schist, hornblende schist, chlorite, — giving their general construction.

CHAPTER III. — Give some ready means for determining in the field such rocks as sandstone, limestone, shale, granite, etc. What is the significance of ancient ripple-marks, raindrop impressions, and footprints? Explain the terms "strata," "stratified," and "sedimentary," and point out their significance in connection with the building up of rock-masses. What is the normal position in which rock-masses are deposited?

How is a departure from the normal horizontal position brought about? Explain rock-folding, and point out its relation to a definite condition of our planet. Represent the different positions occupied by rock-masses; define the term "dip," giving a practical illustration of its meaning by folding a piece of paper to represent it.

CHAPTER IV. — What first characteristics are taught by mountain regions? Illustrate the method of the making of certain mountains and mountain chains. What is understood by a "folded mountain"? Clearly point out the relations existing between mountain backbones and original "longitudinal" valleys. Define the terms "strike," "anticline," and "syncline," and represent these structures through the folding of a piece of paper. Indicate some of the complexities of mountain structure. What is understood by mountain travel or "shearing"? Explain the nature of dislocations and "faults." Give your understanding of the sectioning up or dismemberment of the earth's crust, defining the features known as "fallen troughs" and "continental buttresses" (or horsts), and illustrating these by citations of structure obtained from different continental areas. Indicate the relations existing between crustal breakages and mountain-making.

Give by name such mountains as define the terms "old" and "new" mountain, etc. Describe the work of the atmospheric waters, and point out its relation to the making of scenery. What are earth-pillars and "buttes," and how do such topographic features originate? Cite some localities of their occurrence. Explain what is meant by "aqueous erosion." Give the relation of ravines and gorges to water-action. Define the terms "base-level of erosion," and the structural feature known as "peneplain." Describe a cañon, and indicate the region where cañons are most largely developed.

Clearly define the terms "old" and "new" as pertaining to the features in a landscape. Explain the nature of valleys in a complicated mountain region, pointing out the changes in position and relation which they undergo. How are "transverse" valleys formed? Explain the nature of "mountain (or "water") gaps," and cite localities where such gaps are found. Describe the nature of river-terraces, and point out their relation to the course of a river and to its flood-plain. What relation does a lake basin bear to the stream that discharges into it? Define the process of silting, and point out the ultimate result that is obtained in this process. Give the relation existing between many meadow-lands and lake basins. Give the origin of lake basins, with special reference to the work of glaciers. What are "crater lakes"? Explain the land-locking of certain lakes. Interpret the nature of desiccating lakes, and the condition of salinity that accompanies the contraction. Illustrate the positions of some of the ancient lakes of the North American continent, pointing out their relation to existing bodies of water. Name some of the lakes of the Great Basin. Analyze the scenery of lake-shores.

CHAPTER V. — Describe the position of the snows on the Alps. What is understood by the "snow-line," and where does it lie in different parts of the earth? State what becomes of the mountain snows, and give some approximation to the thickness in which it occurs. Describe generally a Swiss glacier. What do the "*crevasses*" and "*séracs*" represent? Define a "moraine," and explain the nature of glacial "*striæ*" and "erratics." Distinguish between the "lateral" and "terminal" moraines. Give a description of the general aspect of a glacier. Indicate the special characteristics of glacial ice. What are "*gletscherkorn*" and "*névé*" (or "*firn*")? Describe the origin and method of formation of a glacier. What is understood by the "*névé-* (or "*firn-*") basin," and where is it found? What are "compound glaciers"? Define the "medial" moraine.

CHAPTER VI. — Describe the motion or "flow" of a glacier, giving some of its special characteristics. What is understood by the term "regelation"? Give some illustrations of the rate of movement of certain glaciers, and the conditions which determine this movement. Describe the mechanical work that is being performed by a glacier — the scouring and polishing of rocks. Define the "*roches-moutonnées*." Indicate the possible relation existing between glacial scour and the making of rock lake basins. What is understood by "drift," and what relation does it bear to glacial work? What is "ground-moraine" (or "till"), and what other special features are associated with the glacial landscape ("drumlins," "kames," "eskers")?

Explain the condition of the "retreat" of glaciers. How does a glacier in recession conform to its terminal moraine? Give the distribution and dimensions of existing glaciers. Enumerate some of the largest glaciers of the world, and give an approximation to the possible thickness of ice out of which they are composed. Give the evidences of past continental glaciation. Define the "Great Ice Age." Illustrate by means of a map the direction of movement of the ice of the Great Ice Age (or "Glacial Period"). State the probable points of departure of the ice in both Europe and North America. Define the "great terminal moraine," and point out some of its relations to the lakes which are now found within its boundaries. What is understood by the morainic "lobes"? What may have been the cause of the Great Ice Age, and what the measure of time that has intervened since its disappearance?

CHAPTER VII. — Explain the nature of mineral waters, and cite some of their distinctive types. On what condition is the quantity of the mineral salts largely dependent? Describe the methods of the formation of caves, and name some of the largest and best-known caves. What are "cave-rifts" and "bone-caves"? Mention some of the most noted bone-caves of the world, and enumerate the animal forms that are most largely associated with them. Explain the nature of "natural bridges." Define the terms "stalactite," "stalagmite," and "stalagmitic crust." What is an "ice-cave," and under what special conditions may its deposits of ice have accumulated?

Explain the nature of "hot springs," and approximate the temperatures which mark some of their waters. State the relation existing between high water-temperatures and the internal temperature of the earth. What is a geyser, and how does it most markedly differ from the ordinary hot springs? Explain clearly the parts of a geyser — the geyser "cone," vertical conduit, top-basin, etc. Enumerate some of the best-known geysers, the localities of their occurrence, and the dimensions of the special parts. What is understood by siliceous and calcareous "sinter"? Mention some of the most famous geyser deposits.

CHAPTER VIII. — Give the configuration of the oceanic trough. State its probable origin, and give the evidence in favor of considering it an area of weakness in the original crust. To what extent are the continents and oceans permanent or non-permanent in position? Cite some facts indicating or proving the disruption of continental masses. Give the configuration of the Atlantic basin, with a statement of its depths, and the relation of its several projecting ridges. What is understood by "inconstancy of the ocean-level," and to what degree may this inconstancy be developed?

Define the nature of "oceanic transgressions" and "oceanic recessions." Define the nature of a "drowned land," and of "drowned waters." Illustrate the latter condition by reference to some of the American rivers.

Analyze the conditions that are taught by the terms "submergence," "positive subsidence," and "apparent subsidence." State the nature of fjords, and point out their relations to the valleys of the land-surface. What are "ocean terraces," and what broad fact do they teach? Describe the wear of the coast-line, and name some of the features that are incised into it as the result of the oceanic distruction — "ovens," "blow-holes," etc. What is the "plain of marine denudation," and in what respect does it differ from the "peneplain"? Illustrate the breaking up of coast-lines through the encroaches of the sea, citing prominent instances where a dismemberment of the land has been brought about. Give some instances of the destroying power of the sea. What do we understand by the "sediment" and "sediment discharge" of rivers? Indicate how the sediment discharge of a river may be measured or determined, and point out what relation this sediment bears to the drainage-basin of a river. Give an approximate rate of "denudation" of the land-surface. In what way does the sediment carried out by rivers help to make new land? How does the wear and tear of the coast-line help to make new land? Cite some instances of the encroaches of the land upon the sea.

CHAPTER IX. — State the probable condition of the earth's interior. Give the approximate rate of increase of temperature in the interior, and indicate what influence, if any, this temperature has upon climate or the surface of the globe. What effect has pressure upon the liquefaction of rock-masses? What are the assumed "pockets of molten material"? Give the density or weight of the earth, with a statement as to the possible condition or character of the rock-masses of the deeper interior.

CHAPTER X. — Describe the general aspects of a volcano, clearly defining its special parts, such as the cone, crater, conelet, etc. Describe the operations of a volcano, and detail the changes that are brought about by work in progress. What is understood by the volcanic neck or "funnel"? What is understood by the "smoking" of volcanoes? Detail the inner construction of a volcanic mountain. Enumerate the kinds of materials that are discharged by a volcano, and indicate their relations to the building up of the mountain. Give the dimensions of some of the largest volcanoes, and the proportional amounts of material that they throw out. Specify the characters of "composite," "cinder," and "ash" cones. Define "lava," "scoria," "ash," and "tuff."

Explain the working activity of the volcanic mountain. What is understood by the condition of being "extinct," and what changes or new structures in the mountain accompany extinction? Indicate the difference between a paroxysmal and a non-paroxysmal eruption. Explain the nature of the "crater-ring." State the methods of the decapitation of a volcanic mountain. What is meant by the "shifting" of the points of activity? Define the nature of "parasitic cones" and of volcanic "dikes." Give the after-history of a volcano. Give the nature of "crater-lakes," and mention some of the better-known water-basins having their character. Explain what is a volcanic "neck" or "plug."

State the possible cause of eruption. Describe the nature of fissure eruptions, and name some of the localities on the earth's surface where such eruptions have taken place. Explain the meaning of "trap." Define a "dike." Explain the nature of "laccolites," and state where such are found.

CHAPTER XI. — Give the distribution of modern volcanoes, with reference to the two main belts of their occurrence. What characteristic in their distribution is specially emphasized. Enumerate some of the loftiest and most active cones. Define an earthquake, and indicate some of the ways in which earthquakes are produced. What relation exists between earthquake and volcanic phenomena? Illustrate the relation existing between land-slipping and earthquakes. How does the abstraction of material from the interior of the earth affect the surface? Give the probable depth of origin of an earthquake, and state the possible extent to which the earthquake impulse may be propagated. What is understood by the "earthquake-wave"? Describe the passage of the earthquake-wave, and indicate some of the conditions by which it is determined or regulated. What is the extent or intensity of the earthquake movement? Cite instances where permanent land-displacements have followed earthquakes. Give the nature of the oceanic or "tidal wave" which is frequently associated with earthquakes. Give the velocities with which the terrestrial and oceanic impulses are transmitted.

CHAPTER XII. — Describe the aspects of a coral reef. Describe the making of coral land, and give the special conditions which govern the life and distribution of the reef-building coral. What do we understand by the wind-drift or æolian character of coral sand? Name the different kinds of coral islands and reefs, — "atolls," "barrier-reefs," "fringing-reefs," — and clearly indicate their differences and similarities. Define the parts of an atoll, — "lagoon," "ring" or collar, etc. Explain the occurrence of reef-structures in the deeper waters of the ocean, with special reference to the "subsidence theory" of coral formations. What may be the probable thickness of the coral-made rock? Explain the nature of organically constructed oceanic "banks," or "platforms," with reference to the physics of certain reef-structures. Explain the nature and condition of existence of "elevated reefs." Give the distribution of modern reefs, citing some of the best-known examples of their occurrence. Give the distribution of some ancient reefs.

CHAPTER XIII. — Define a fossil, and cite examples from both the organic and the inorganic world. State the manner of occurrence of fossils, specially defining the conditions known as "casts," "moulds," and "impressions." What do we know of the preservation of fossils and of their special markings (color, etc.)? What is understood by "progression in structure" in the organic chain? Give a synoptical review of the order of occurrence of some of the principal animal types. What is understood by the "doctrine of evolution" as pertaining to organic forms? Define the "time-standard" of geological history. Explain "variation" and "extinction" in animal forms. What is understood by "natural selection"? What is the "struggle for existence"? Define "disappearance" and "reappearance." Define a geological "horizon." What is a leading- or "type-fossil"?

Give (from the table) the names of the main "epochs," or "formations" belonging to these epochs, which are recognized by geologists. Enumerate some of the more distinctive fossils that belong to each of these. About where do the fishes make their appearance — the amphibians, reptiles, birds, mammals? Where does man belong? How far back in time does a land-vegetation extend? What were some of the earliest insects?

Define the different kinds of fossils — marine, terrestrial, and fresh-water, and state their mutual relations to one another (or the probable lines of their origin). Briefly characterize, from a faunal aspect, the faunas of the different periods, — Cambrian, Silurian, Devonian, etc., — and emphasize their relations to one another from the point of view of the evolutionist and of progressive development.

CHAPTER XIV. — Give the organization of some leading groups of fossils, — "Foraminifera," corals, "trilobites," "crinoids," etc.

CHAPTER XV. — Give your knowledge regarding fossil fishes, reptiles, birds, and mammals. Define the nature of the "Pterodactyls," of "Archæopteryx." What were the "Odontornithes"? Outline the order of appearance and succession of the Mammalia. Give the broad origin of the existing faunas of the globe. What is understood by "ancestral forms"? and cite an instance of modification through descent. State something about the antiquity of man, and of his association with the mammoth and mastodon. Where have ancient remains of man been found, and what do they indicate?

CHAPTER XVI. — Give the physiognomy of some of the continental areas of the globe. What relation exists between mountain lines and seashores? Define the different types of coast-line. Give the physiognomy of mountain masses, in their aspects of ridges, valleys, general contours (slope, etc.), age, and scenery. Define the terms that are frequently applied to different parts of a mountain, — "col" (or "Juch") "arête," "aiguilles," "couloir," "massif," etc. Define the "anticlinal," "synclinal," and "monoclinal" mountain. What is understood by the term "fault block"?

Give the physiognomy of plateaus and of "plateau mountains." Where do examples of the latter occur? Explain the difference between the "mountain plateau" and the "continental plateau." Give illustrations of both structures. Describe the nature of the Greenland and Mexican plateaus. Give the physiognomy of valleys, clearly characterizing "plains" and valleys proper, and the different modifications of the latter. Define the V-shaped valley, the U-shaped valley, and the glacial valley. Give the physiognomy of the coast-line, and state the relation existing between coast-lines and mountain chains. What do open and closed coast-lines specifically indicate? What do "hooks," barriers," and detached headlands and rocks signify?

Give the physiognomy of rock-masses — their positions in the field and relations to one another. Define the terms "anticline," "syncline," "monocline," "dip," "strike"; how are the conditions of these structures brought about? What is understood by "unconformity"? What is a geological "break"? State some of the special characters impressed upon rock-masses. Explain "current-bedding" and "flow-and-plunge" structure.

CHAPTER XVII. — Give the characters and modes of occurrence of some of the more useful metals and minerals, such as gold, silver, copper, lead, iron, etc. Enumerate the most serviceable ores of the principal metals. Describe the method of coal formation, and give the condition of the United States (in part) during the making of its coal. Name some of the most distinctive plants of the coal-period. Give the areas of the principal coal-fields of the world. Give the production of coal. Enumerate the principal varieties of coal, and state their characteristics. Define petroleum and "natural gas." State something about the production of these substances. What is "bitumen" or "asphalt"?

CHAPTER XVIII. — Give some of the special characteristics and requirements of building-stones. Enumerate some of the better varieties or classes of such. What are some of the deficiencies in building-stones? Give your knowledge regarding "flagging-stones," roofing-slates, and "tile-stones." Define and characterize clays and soils. What is understood by the terms "glacial drift," "bowlder-clay," "till," etc? What are "marls" and "loams"? Describe the "greensands" of the Atlantic slope of the United States. Enumerate some of the most efficient fertilizers — lime, guano, phosphates. Where do some of the richest phosphate beds occur? Define a "bone-bed."

CHAPTER XIX. — Name the most important rock-forming minerals, and state how they occur, and what special rocks they form. Enumerate the more important varieties of quartz, and give their chemical composition and distinctive characters. Give the general characters and composition of calcite, feldspar, hornblende, mica, etc. What is the "scale of hardness," and how is it constituted? Name and briefly define some of the more important gem-stones, as emerald, diamond, ruby, etc. Mention other accessory minerals of rock-masses.

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